

# The Role of Pre- and Post-College Education in Preparation of Engineering Professional and the Concept of Teaching Factory

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**Abstract:** The time-span for college education of engineering graduates is very limited (3.5 to 4 years), compared to time required for professionals in other fields, such as medical and pharmaceutical fields for instance. During this limited period it is very difficult, to adequately satisfy the modern sophisticated industry and the knowledge-based economy requirements of a graduate engineer. Here, the role of pre-college or school (K-12) education and the post-college education, such as continuing engineering education, becomes significant. In this paper we consider the role of each of these stages in the development of skills and competencies needed by engineering professional and introduce a concept of teaching factory and its role in complementing formal engineering education.

**Key words:** K-12 education, professional engineering preparation, engineering skills, attributes and competencies, teaching factory

### 1. Introduction

There is a vast amount of skills and attributes required of an engineering graduate in order to tackle the complex problems of the modern society and this puts heavy burden on engineering institutions and engineering education policy makers. In order to shed light on the type and complexity of modern society problems, we look at some examples of engineering products encountered in everyday life. In the automobile industry, for instance, you may find over fifty types of sensors and associated microprocessors involved in carrying out different automation functions. Another example is the familiar everyday companion piece of electronic device, the cell phone, which now posess processing power of a super-computer of early seventies of the last century. These are just two simple examples of engineering products of everyday use, let alone the sophisticated systems of industrial plants and self-guided missile and other military gadgets. Apart from the complexity of the engineering systems themselves, there are many other factors such as environmental, social and economical that have added to the complexity of engineering problems of the 21st century.

This complex structure of modern products and their multi-disciplinary nature, requires a vast amount of knowledge outside the domain of traditional training in basic sciences, mathematics, and technology, and goes all along the way through managerial and economic sciences, ending with environmental, safety and ethical issues. Now comes the obvious question; Can this large amount of knowledge, skills and competencies be adequately

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developed during the limited period of 3.3 to 4 years of college education?

This is what we will try to explore in this paper, which starts in section 2 with an overview of the knowledge, skills and competencies, of a graduate engineer, needed by modern sophisticated industry and services. This is followed, in section 3 by the challenges that face engineering curriculum designers. In sections 4 we discuss a proposed method to tackle the time constraint of the college engineering education, and in section 5, we introduce the concept of teaching factory, together with its role, in assisting engineering institutions in proper and adequate preparation of engineering professionals.

## 2. Skills and Competencies of Engineering Professional

Apart from mathematics, basic and engineering sciences and technology knowledge and skills, for which engineering professional are usually trained, employers in industry and accrediting bodies of engineering programs, are now asking for more and more skills; such as effective communications, team work and leadership, ethical issues, decision making, adapting to globalization and environmental conditions and modern tools (computers simulation) to solve problems, preparation for continuing and life-long learning, knowledge of project management, finance and principles of economics.

A vast amount of research has been carried out in many aspects of the required skills, competencies and attributes of future engineering professionals (ABET, 2014; Nasr Karim J., 2014; Sharafi S., Bassak Harouni G., Torfi S. Makenalizadeh N. & Sayahi A., 2011; Laker D. R., & Powell J. L., 2011; Shuman L. J., Basterfield-Sacre M., & McGourty J., 2005). These skills and competencies can, in general be divided into two main categories; hard (technical) and soft or professional skills (Sharafi S., BassakHarouni G., Torfi S. Makenalizadeh N. & Sayahi A., 2011; Laker D. R., & Powell J. L., 2011). The hard or technical skills include proper training and foundation in mathematical and basic sciences, basic engineering sciences (design and modeling) formulation and analysis of complex problems in addition to engineering technology such as workshop skills and engineering graphics. These are specified in Criterion 3 of ABET as ability to ABET (2014): apply knowledge of mathematics, science, and engineering; design and conduct experiments, as well as to analyze and interpret data; design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; identification, formulation, and solving engineering problems; and the use of techniques, skills, and modern engineering tools necessary for engineering practice. These are mainly attained at the college level education, and are, in part based on pre-college or school preparation of potential engineering students.

The soft skills, on the other hand, include all those required skills and attributes summarized in six of the eleven ABET students outcome namely; an understanding of professional and ethical responsibility; ability to function on multi-disciplinary teams and communicate effectively; the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; recognition of the need for, and an ability to engage in life-long learning; and knowledge of contemporary issues. For the discussion of the complete set of required engineering graduates' skills and competencies, the reader is referred to the comprehensive review given by Nasr (2014).

## 3. Challenges that Face Engineering Curriculum Designers

The challenges that face engineering curriculum designers regarding preparation of future engineering

graduates well versed in the required skills and competencies needed, are overwhelming. However, for the purpose of illustrative discussion we can summarize them briefly in the following:

## 3.1 Time Constraint

According to ABET for instance, an engineering program curriculum should include: One year of college level Mathematics and Basic Sciences; One and a half year of engineering topics (Engineering Sciences and Engineering Design) in addition to a general education component, typically taking about one year. This adds up to about a minimum of 3.5 years to 4 years, equivalent to about 128–132 credit hours of training depending on the type of engineering program discipline.

As illustrated above, the required basic and core courses, in addition to General Education courses, swallow the whole time-span of the curriculum, leaving no room for inclusion of any other courses required to cover foundation for other required skills and competencies, especially the soft skills. Also looking back a few decades ago at the time span required for preparation of engineering graduates at college level shows that it has remain almost constant, compared to other professions, such as medicine, law and pharmacy as shown in Figure 1 (Agogino A., 2014). Due to this limited period of formal engineering education, some experts, like Agogino (2014), went far and suggested considering Bachelor engineering degree (BS) to be recognized as pre-engineering degree followed by a further education, such as Master's degree, depending on the course content and career aspiration of the student.





#### 3.2 Engineering Student's Background

Although many engineering institutions impose a set of entry requirements to their engineering programs regarding the mathematical and basic sciences background, one of the basic problems facing new engineering students and cause large percentage of drop-outs, and hence low attrition rates, is the lack of proper preparation of these students in mathematics and basic sciences at their early school education.

#### **3.3 Rapid Change in Technology**

The rapid changes in technology and the need to incorporate them in the curriculum, so that the engineering

graduate becomes aware of the new trends in technology presents a real challenge in terms of both physical and human resources needed to accomplish this task.

## 3.4 Incorporation of Soft Skills

Incorporation of soft skills mentioned above in the already crowded curriculum calls for extended period of time required to include appropriate topics, at the college engineering educational level.

## 3.5 Engineering mobility and globalization

The new trend of globalization and global market requires more sophisticated skills and interdisciplinary knowledge in addition to innovation and intellectual teamwork, and this again calls for extended period of education and introduction of new methods of instruction and training (Sharafi S., Bassak Harouni G., Torfi S. Makenalizadeh N. & Sayahi A., 2011).

Among all the above challenges, the time constraint is the most critical one, as it has its own implications on all other challenges. In the following sections, we elaborate on ways and means of tackling this problem of time constraint.

## 4. Proposed Method to Tackle Time Constraints

In order to tackle the time-span constraint facing incorporation of more topics needed to satisfy required skills and competencies of future engineering graduates, we need to consider engineering education as a system or part of a system of systems. The role of engineering education at universities and colleges is only a part of a long chain of roles played by different parties (sections); starting from school, passing through technical colleges and universities, and ending with engineering association, societies and accrediting bodies.

This long chain of connected parts is surrounded by many outside compelling forces such as (Figure 2); rapid technological changes and the challenges they represent, the requirements of the modern knowledge-based society and economy, in addition to other safety and environmental pressures.



Figure 2 Engineering Education Pathway and Surrounding Affecting Factors

In the following sub-sections we consider the main parties that can positively contribute to the preparation of

the engineering professional and the role that can be played by each party (Figure 3).



Figure3 Engineering Education Pathway and the Role Played by Each Participating Party

## 4.1 Pre-College or School Education

The secondary school (K-12), or an equivalent, can play a significant role in preparing the potential engineering student in basic science and mathematics, by laying the first building bricks upon which strong foundation in these disciplines can be built in the early stages of the college education. This is where the basic concepts of basic sciences and mathematics have to be emphasized and clearly communicated to the student. Experience with students at the early stage of college education showed the lack of many students of the basic concepts of mathematics and basic sciences, due to inappropriate preparation at school level. Moreover, majority of students falling under probation and students drop-outs can partially be attributed to the lack of basic concepts in these disciplines.

Quality of students entering engineering colleges/schools is one of the input indicators used for evaluation of engineering education world-wide. In their comparative study of the quality of engineering education in the BRIC countries and the US, Loyalka et al. (2013) attributed the competitiveness of engineering graduates in these countries, compared with those of the world developed countries despite their lower scoring in other input indicators of equality of engineering graduates, such as financing of and availability of qualified faculty, to the quality and amount of mathematics and science courses at high school. Polastri (2014), in her study of developing globalized and sustainable mindset in 21st century engineering students' attributed the reason for US students leaving engineering as a preferred area of study, to the level of mathematical skills required in the engineering curriculum. This level of mathematical and scientific skills cannot be adequately attained at college level, unless the student is well prepared early at the secondary school level.

Therefore, a strong link between engineering colleges and high school should be established in order to strengthen basic science and mathematics at high school curricula, and professional development of high school teachers in these areas. This can be readily incorporated in the already being investigated STEM (Science, Technology, Engineering and Mathematics) activities in a number of countries, such as UK, UAE and Qatar to

name only a few examples.

#### 4.2 Post-College Professional Preparation

As always indicated by many employers, an engineering college graduate lacks many of the soft skills and knowledge required by local industries and global job market, such as communication, teamwork, leadership and ethical issues. In order to address this issue many engineering institutes locally, and in many parts of the world introduced what is known as internship, in which a student spends a limited period of about two to three month in industry. However, experience has shown that, this limited period of internship is not enough to cover those required skills, let alone the lack of specific course of training that could be followed by a student during the internship period. Therefore the Internship should be complemented by some post-college professional training.

4.2.1 The Role of Industry and Other Parties

Industry and engineering councils, societies and professional organizations such as IEEE, ASME ... etc. can play a very important role in developing the soft skills needed. As pointed out by Nasr (2014) "The production of knowledge cannot be expected to be done within the walls of educational institutions alone, but rather within the context of shared responsibilities of both academia and industry" ... "learning by doing is essential. Hence partnership between academia and industry becomes an urgent need". Also a study carried out in 2007 by UK Royal Academy of Engineering, showed that academia and industry, came to the conclusion that " ... students need opportunities to work in genuine industrial environment through work placement and projects and university staff need to develop new teaching material with input from companies, learning from the success of academic-industrial research links".

# 5. The Concept of Teaching Factory

In an attempt to find a proper way by which industry and other parties can collaborate with engineering institutes, the author proposes introduction of the concept of Teaching Factory, borrowed from the medical professional field concept of Teaching Hospital. The teaching hospital is usually a public hospital or a special hospital associated with a public or private medical school. The period spent in these teaching hospitals, is termed houseman-ship in some countries and Internship in other countries, and extends to about one calendar year. A physician cannot practice his/her medical profession without satisfying this requirement of houseman-ship. However, the concept of Teaching Factory cannot be readily implemented in the same sense as teaching hospital for many reasons, among which: i) There is no single employing body for all engineering graduates, like the Ministry of health, which is responsible for employment of most, if not all physicians. Engineering graduates are usually distributed among many employing parties, such as; electricity boards, ministries of work or industries, and different types of factories according to their specialization and ii) the teaching factory requires more resources, which cannot readily provided by a single engineering education institution, especially those private institutions, many of which struggle just to make break-even in their budgets. Here comes the role of governments and private sector (industry) and the extent of collaboration between them and the teaching institutions in order to facilitate adequate preparation of potential engineering professional. Government and industry should contribute to the funding of such teaching/training bodies. Investment in such activities will soon payback, as it will considerably reduce expenses of special training of fresh graduates, now carried out by many public and private sector industries and engineering service providers.

## 5.1 Role of Teaching Factory

The role that can be played by teaching factory proposed here is similar, in principle, to the role of the learning factory, introduced in the mid-nineties of the last century, by MEEP (Manufacturing Engineering Education Partnership), with the aim of integrating design, manufacturing, and business realities into engineering curriculum (Morell L., Jorge I., Velez-Arocho and Jose I. Zayas-Castro, 2004). Although the philosophy and concept of the Teaching Factory proposed here and the Learning Factory of MEEP is similar, in that both are based on collaboration between academic institutes and industries, the main difference is that the MEEP Learning Factory concept is based on integrating this collaboration which is based on capstone projects carried out jointly between academia and industry, in the four-year curriculum of college-level education, whereas our proposed concept of Teaching Factory is based on an extended period of education/training of a graduate engineering after completing the college-level prescribed curriculum. Here the engineering graduate can continue his/her training period as engineer under training, and work in solving/designing real-life problems under close supervision of senior engineers. This will also enable him/her to be acquainted with decision-making, ethical issues and safety considerations.

## 6. Conclusions and Recommendations

In this paper, a survey of the skills and competencies required of an engineering professional and the role that can be played by each of the pre-college or school education and the post-college professional development were given. The concept of Teaching Factory, similar to the Teaching Hospital, in the medical field, has been proposed, and its role in proper and adequate preparation of the engineering professional has been briefly discussed. More thoughtful work and elaborated research is needed in order to properly conceptualize the role that can be played by the Teaching Factory in bridging the gap between the basic education and training provided by engineering institutes and the requirement of the globalized modern knowledge-based economies of the 12st century.

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