Engineering Education 21st Century and Beyond

Author (Shammah Kiteme Munyoki)[1]

[1] CengProm Services Ltd, P.O. Box 38472-00100, Nairobi

Abstract
There has been a significant advancement in the theory and practice of Engineering. From antiquity where foundational understanding of solid mechanics started, Archimedes (287-212 B.C) published his works on the Equilibrium of Planes. He argued that equal weights at equal distances are in equilibrium, to the medieval times where the engineer in the 15th, 16th and 17th centuries was defined as someone who looked at fortifications and artillery. There were engineers in continental Europe mainly in Spain, Italy, France and Netherlands. From military engineering to civil engineering the theory and practice of Engineering has truly evolved from the early research in solid mechanics to the modern complex finite element analysis methods. This evolution now converges in the era of Artificial Intelligence, Machine Learning and Internet of things. The Engineer will remain highly regarded in the society yet societal dynamics are evolving such that Engineering education must similarly evolve to produce the Engineer at graduation who is capable of playing the effective role in the society without being send to the backburner by the fast-evolving society. This paper will dwell on what needs to be done in bridging the gap between academia and practice in a manner that produces robustly equipped Engineers for the practice of Engineering in 21st Century and Beyond

Keywords: Engineering Education, Graduate Attributes, Initial Professional Development, Professional Competency, Lifelong Learning.

1 Introduction

Between 5000 and 4000 BC, the Sumerians and Akkadians occupying the present-day parts of Iraq developed irrigation systems using canals. Ancient Mesopotamia also developed metal tools and weapons as well as two-wheeled carts. Along river Nile, Egyptians begun to build with stone the precursor to the eternal marvels that are the pyramids built by Imhotep[3]. The first pyramid was built around 2700 BC and they are a testimony to the Engineering genius of ancient Egypt. Engineering was also being practiced in other areas like India and China. Military Engineering excelled and the Great Wall of China is good evidence. By AD 105 paper printing through very rudimentary methods was happening in China. The Inca of South America, the Maya Civilisation are evidence of Engineering in practice in antiquity[3].

With the continuing of settling of man communities emerged and competition of resources as well as identity of groups and communities led to war. From here military engineering emerged. Military engineering involved itself in building defense walls, other fortifications as well as armaments for war[2]. It became important where the king stayed and often the palaces were built in the hills for ease of defending the palace. That is a strategic military decision of the time.

The engineer in the 15th, 16th and 17th centuries was defined as someone who looked at fortifications and artillery. There were engineers in continental Europe mainly in Spain, Italy, France and Netherlands[2].

Structural engineering and Architecture in Middle Ages was largely done by masons and carpenters. These were largely artisans and it was a tradition carried over from the ancient civilizations. They worked on the experience of what had worked before and so the theory of structural engineering as we know it today was not existing[2].

Engineering schools emerged in Continental Europe. Germany, France, Italy. The theory of Engineering was fast evolving and notable names like Galileo Galilei, Leornardo da Vinci, Leornard Euler were key contributors in advancing this. In 18th century John Smeaton defined civil engineering to distinguish it from what was military engineering[2].

With time the various divisions of Engineering emerged and there are various names attributable to this. Charles Augustine de Coulomb, Michael Faraday, Thomas Young among others did foundational works. These are what we can call genius of our profession. They developed whole, or part Engineering theories. Others still built on previous works and further advanced the understanding of the abstract concepts that we today appreciate as Engineers.

2 Discussion

The International Engineering Alliance has developed the Graduate Attributes and Professional Competency that Engineers must attain for them to be fit in delivering professional services as Engineers. This involves an outcome-based criteria for evaluating engineering programs. The graduate attributes are indicative of the graduate's potential to acquire competence in practice at the appropriate level[1]. Table 1 lists the graduate attributes

Table 1. Graduate Attributes

Graduate Attribute	**Expected Abilities**
Engineering Knowledge	The graduate is supposed to develop a breadth, depth and type of theoretical and practical knowledge and apply mathematics, natural sciences, computing and engineering fundamentals. It is expected a graduate will develop solutions to complex engineering solutions.
Problem Analysis	Using first principles of mathematics, natural sciences and engineering sciences and mindful of sustainable development, the graduate should carry out analysis of complex engineering problems reaching substantiated conclusions
Design/Development of Solutions	The graduate should be able to design systems, components and processes to meet identified needs. In doing this a graduate should consider public health and safety, whole-life cost, net zero carbon, cultural, natural and environmental considerations
Investigation	The graduate should be able to carry out investigations of complex engineering problems using research-based methods like design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions
Use of tools	Understanding appropriateness of technologies and tools. Recognising limitations of appropriate techniques resources and modern engineering and IT tools. And their application to predication and modelling of complex engineering problems
The Engineer and the World	The graduate should demonstrate level of knowledge and responsibility for sustainable development. Mindfulness to the society, economy, sustainability, health and safety, legal frameworks and the environment
Ethics	Applying ethical principles and committing to professional ethics and norms of engineering practice and adherence to relevant national and international

	laws. Consideration for diversity and inclusion.
Individual and Collaborative Teamwork	Ability to function effectively as an individual, and as a member or a leader in diverse and inclusive teams in multi-disciplinary, face to face, remote and distributed settings.
Communication	Ability to communicate effectively and inclusively on complex engineering activities with the engineering community, the society at large. Writing effective reports and design documentation. Making effective presentations considering cultural, language and learning differences
Project Management and Finance	Understanding of engineering management principles and economic decision making. Applying these as a member or a leader in managing projects in multi-disciplinary environments
Lifelong Learning	Cultivating independent and lifelong learning, adaptability to new and emerging technologies, critical thinking in the broadest context of technological change

Source: International Engineering Alliance

It is important for Engineers to learn how to code. Our graduates must be able to write codes. We need to produce a population of engineers who can code and develop transportation modelling, multicriteria decision making in solving complex engineering problems. The repetitive calculations we do can very easily be automated and we write our own formulas. Why must we always depend on software designed elsewhere? If you look at the emergence of big data analytics. Data intelligence is the future of complex decision making and future prediction of patterns. This creative decision making and prediction will be very key in making intelligent business decisions. Artificial Intelligence, machine learning, Internet of Things and other concepts like digital twining is going influence largely asset management and designs. What we do repetitively can be trained on a machine to make automatic decisions and limit human involvement.

We must teach engineers how to engage in public policy formulation. Understanding the abstract engineering concepts and how they interrelate and affect the society is not enough. Engineering theory and practice must become relevant to the society. This largely happens through policy formulation. The succession of policy making involves and idea, this idea is reduced into a policy and the policy is enacted and implemented through legislation or administrative actions. Engineering needs to meet the needs of the society and for this to happen we must equip our graduates with the skills to influence, initiate and effect polies in the private and public sectors

Let us train our engineers on project management skills. Many of us end up in projects and we need to be natural leaders in the project area. We are most likely to make mistakes in projects that we will live with. Construction involves reducing design concepts into reality. When the design is not correctly implemented mistakes occur. Careful thought and planning must go into project before we even hit the ground. Projects have a life cycle. They have initiation stage, planning stage, execution, monitoring and evaluation and closing. Projects must have a beginning and an end and they should produce a service, product or an outcome initially desired. Project also require an integrated understanding of many other areas of specialties that are not essentially Engineering. Project Cost, Project Risk, Quality, Project Schedule, Project Procurement Management, Project Communication and change Control are some of key areas that an Engineer must get well acquainted with. We must have project charter and develop a good project management plan for instance. These skills must be passed on to our Engineering graduates

As pointed out that Procurement is another area we must understand in the context of project management, it follows that it will affect us a lot in our practice. If we have engineers exposed to basic principles in the practice of procurement much of the shock engineers get when in practice and they find a very powerful procurement department would cease. Almost every aspect of organizations is nowadays affected by procurement. From acquisition of consultants, procurement of contractors to purchasing of engineers software and other tools of trade we use as Engineers procurement is involved in one way or the other. We need to know which procurement process should be used and when.

Basic finance is another area where engineers have to develop basic skills. Universities need to help engineers know how to make simple financial decisions like return-on-investment, Internal Rate of Return, Cost Benefit Analysis as well as the decisions like Cost Variance and Schedule Variance in projects. Other important aspects of making decision like To Complete Performance Index, Cost Performance Index, Schedule Performance Index and Life Cycle Analysis must become the comfortable area for Engineers before they exit the campus or during the Initial Professional Development in their careers.

Engineers need to be trained as leaders. We have absconded the roles and left it to other players in the built environment. Leaders curve their space and assert themselves. We must begin inculcating this to our graduates. Leadership must be sensitive to diversity. One challenge we engineers have is that we work with principles. We work with formulas to arrive at conclusions. Leadership sometimes takes making decisions in a very unpredictable situation. This involves making decisions and leading in volatile situations, but also having complexity in decision making and involving a lot of ambiguity. Mostly leadership involves inspiring change and growth. This comes with a certain degree of unknowns. If we are only comfortable behind the design software then the decisions that affect us significantly will continue to be made by others. We must get comfortable taking those hard decisions. We must also be comfortable to try and fail. There is no learning without trying new things. We need to inculcate this level of dynamism to our graduates

Let us built in Engineers self-esteem, some other professions one of the life skills they seem to have is confidence. Self-confidence takes you far. The saying that fortune favors the bold (Virgil c. 19 B.C) has credence. We must not go around subdued as if waiting for someone to come to our aid. We must knock doors. We must claim our space. We must plant it in our candidates that everything is there for our taking and we must go for it. The recent developments where the jobs that Kenyan Engineers are qualified to do are carried out by foreigners has been a great demoralizing force to many engineers. We must get to a place where doctors protested when the government of Kenya decided to bring in doctors from Cuba. When the office of the director of public prosecutions tried to hire a lawyer from out of the country, there was an outcry form the legal fraternity. The lawyer never set their foot here to practice.

The engineer after graduation will be expected to undergo initial professional development and a number of competencies are expected from them. Table 2 lists these professional competencies as detailed by the International Engineering Alliance

Table 2. Professional Competence

Professional Competency	**Expected Skills**
Comprehend and apply universal knowledge	The engineer must comprehend and apply advanced knowledge of the widely applied principles underpinning good practice
Comprehend and apply local knowledge	The engineer must comprehend and apply advanced knowledge of the widely applied principles underpinning good practice specific to the jurisdiction of practice
Problem Analysis	The engineer must be bale to define, investigate and anlyse complex problems using data and information technologies where applicable
Design and development of	Taking account of stakeholder views, the engineer must be bale to design and

solutions	develop solutions to complex problems
Evaluation	The engineer must be able to evaluate the impact and outcomes of complex activities
Protection of the society	The engineer must recognize the foreseeable economic, social and environmental effect of their complex activities and seek to achieve sustainable outcomes
Legal, regulatory and cultural	The engineer must protect public health and safety and meet all the legal, cultural and regulatory requirements in all of the activities
Ethics	The engineer must be able to conduct their activities ethically
Manage engineering activities	The engineer must be able to manage part or all of the complex engineering activities
Communication and collaboration	The engineer must communicate and collaborate using multiple media clearly and inclusively with all stakeholders in all activities
Continuous professional development and lifelong learning	The engineer should undertake CPD activities to maintain and extend competencies and enhance ability to adapt to changing technologies and evolving nature of work
Judgment	The engineer must exercise sound judgment in decision making recognizing complexity and assessing alternatives
Responsibility for decisions	The engineer becomes responsible for making decisions on part or all of complex activities

Source: International Engineering Alliance

3 Conclusion

Engineering Education must produce multi-skilled engineers. This will be required so that we can fit in the ever-evolving world. A culture of lifelong learning is also going to be vital for every engineer. As engineers we must claim our position in the society. That position of leadership is there for us to take. Table 3 gives an example of training areas that Engineers can engage in lifelong learning

Table 3. Engineers Lifelong learning

Graduate Engineers[5]	**Professional Engineers**[6]	**Consulting Engineers**[6]
Communication	Business writing	Leadership and Influence
Self-management	Developing High Performing teams	Strategic Leadership
Emotional intelligence	Negotiation and Dispute Resolution	Policy and Governance Influence
Resilience	Technical writing	Serving in Boards effectively
Project Management Lifecycle	Procurement and Tendering	Political lobbying

Problems Solving	Managing Engineering Knowledge	Lifelong learning
Stakeholder engagement	Project Management certification	Writing books and Memoirs
Risk management	Financial acumen for Engineers	Re-investing back
Leadership	Managing Teams and stakeholders	Community engagement
Innovation	Leading Projects in Crisis	Mentoring the next generation
Team work	Advanced Contract Management	Transition from manager to leader
Critical Thinking	Business Risk in Engineering	Managing Change in organizations

Source: Engineering Education Australia and Author

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