Engineering Curriculum for a Global Village

Roop L. Mahajan
Lewis A. Hester Chair Professor
Department of Mechanical Engineering
Virginia Tech, Blacksburg 24061
USA

Abstract

At a 2003 Energy & Nanotechnology Conference at Rice University, noted scientist and Nobel Prize winner R.E. Smalley presented the following list of the top 10 problems of humanity for the next 50 years: 1) Energy, 2) Water, 3) Food, 4) Environment, 5) Poverty, 6) Terrorism and War, 7) Disease, 8) Education, 9) Democracy and 10) Population. These problems have a few characteristics in common. They are challenging and complex, are interconnected, have a high degree of uncertainty, are global in scope, and require multiple perspectives. For engineers who pride themselves as problem solvers, meeting these challenges demands of them decisions that not only require technical expertise but also a keen understanding of broad, socio-humanistic contexts and considerations. We, in academia, must ask the crucial question: Are we preparing our students to tackle these real-life global challenges?

In this paper, I will address this question and propose that the current curriculum in various engineering disciplines move beyond conventional silo-based contents to holistic programs that integrate interdisciplinary inquiry into the core courses and prepare students for global engagement through the use of overseas student exchanges, global academic partnerships, and emerging technologies. As an example, I will present a curriculum for a four-year Mechanical Engineering degree program that blends human and social sciences, applied sciences, communication and leadership with the required math and core mechanical courses. To introduce students to interdisciplinary research and outreach, the curriculum requires them to undertake a multi-year project(s) to reach out to developing communities locally or globally and assist them in self-reliance through sustainable technologies and practices. I believe that by embracing these more encompassing perspectives in learning and discovery, we will prepare our students for careers addressing global problems.

Keywords: Engineering Curriculum Design, Mechanical Engineering, The next Generation Engineers, Global Challenges

1. Grand challenges facing humanity: Interconnected and global

The recent advances of civilization attributed to science and technology have been nothing less than awe-inspiring. Looking back at the beginning of the 20^{th} century, the country was not electrified; radio, TV, computers, telephone and the internet did not exist; and the average human life span was only 46 years. Much of society's transformation since then has been made possible through technological breakthroughs powered by science and engineering. One could argue that in the last century mankind has seen more change than at any point in history.

However, even as we marvel at the breakthroughs of the last century and continue to build on that progress, the 21st century presents us with a fresh set of daunting problems, challenges, and opportunities to keep scientists and engineers engaged as they look for solutions. As mentioned in the abstract, at a 2003 Energy and Nanotechnology Conference at Rice University, Nobel Prize winner R.E. Smalley presented a list of the top ten problems of humanity for the next fifty years: 1) Energy, 2) Water, 3) Food, 4) Environment, 5) Poverty, 6) Terrorism and War, 7) Disease, 8) Education, 9) Democracy and 10) Population. More than a decade later, the list is as valid, if not more so. In wake of the Great Recession 2007-2009, and the ubiquitous and mobile internet, we can add a few more challenges such as rising inequality, safety, security and well-being, and technological and political disruption to this list[1]. A very recent survey[2] of the 26,000 Millennials from 181 countries on their list of the 10 most critical problems indicates a similar view as indicated in the responses below.

1. Climate change	45.2%
2. Large-scale wars	38.5%
3. Religious conflicts	33.8%
4. Poverty	31.1%
5. Govt. accountability & transparency, and corruption	21.7%
6. Safety, security, and well-being	18.1%
7. Lack of education	16.5%
8. Lack of political freedom and political instability	15.5%
9. Food and water security	15.1%
10. Lack of economic opportunity & unemployment	14.0%

What is noteworthy is that almost all of these problems are complex, interconnected, and global in scope. Nowhere is this interconnectedness more evident than in the challenge of global poverty. According to United Nations data, in 2015, over 700 million people world-wide (9.6% of the total population of 7.35 billion) lived below $1.90/day-the poverty line[3]. By the year 2030, it is estimated that the world population will reach 8.5 billion. Assuming that the poverty rate continues to decline at the rate since 2015, it is estimated that 386 million people will still be living in poverty in 2030[4]. This number can be higher or lower depending on the rate of economic growth. Lifting approximately 400 million people out of poverty will require a substantial economic growth. According to a linear equation[5], there is a high degree of correlation between growth in energy consumption and economic growth. To generate the economic growth needed to meet the basic energy needs of the growing world population, approximately additional 3.5 billion tons of equivalent oil or approximately 45,000 terawatts of power will be required. While efforts are underway to tap sources of renewable energy, a large fraction of this demand by 2030 will still be met by burning coal and oil resulting in increased levels of carbon dioxide, global warming accompanied by large-scale changes in weather patterns (not always benign), the melting of ice in the Arctic Ocean leading to a rise in sea levels with disastrous consequences for coastal communities, disruption in food production, outbreak of new diseases and other predictable and not-so predictable effects. Rockström et al.[6,7] argue that human activities could destabilize biophysical systems and trigger abrupt or irreversible environmental changes that would be deleterious or even catastrophic for human well-being.

While the gravity of the situation cannot be underestimated, as an engineer, and an optimist, I believe that we should get to the task of what we do best—providing solutions to the problems at hand. We should and actually must look at these global problems as opportunities to spur our ingenuity and creativity to develop innovative solutions.

An engineering curriculum for a global village must include subject matter providing a comprehensive understanding of the biggest problems facing our and next generation(s) and provide them to do big science to match the problems. They should go out in the workplace with a sense of responsibility in shaping a sustainable world of tomorrow.

2. Powerful technologies at our disposal

Fortunately, there is a new set of converging and emerging technologies with the potential to provide us answers to these challenging problems, where convergent technologies, as defined in the NSF/DOC report by Roco and Bainbridge[8], refer to the synergistic combination of nanotechnology, biotechnology, information technology, and cognitive science (NBIC). Convergence of diverse technologies is based on material unity at the nanoscale and on technology integration from that scale. The report projects that advances at the intersection of these technologies and their integration offer the promise of improving human lives in many ways.

Further, there is a set of equally empowering emerging technologies such as big data, additive manufacturing (popularly known as 3- D printing), pervasive wireless communication, and bio-inspired science and technology[9]. From petabytes of scientific data repositories, we are now increasingly encountering exabyte-scale problem domains, e.g., in astrophysics, mobile data traffic, and digital libraries. The ages-old approach to manufacturing is being up-ended through new capabilities to ‘print’ whole 3D objects through additive manufacturing. Finally, there remains a significant potential to design materials, devices, and systems based on millions of years of evolution of biological organisms that have experimented with different optimization solutions to difficult problems with complicated high-dimensional objective functions and constraints.

The confluence of converging and emerging technologies and the speed at which they are evolving has brought us to the brink of what is being dubbed as the Fourth Industrial Revolution, which is building on the Third, the digital revolution that has been occurring since the middle of the last century. It is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres, and will alter the way we live, work, and relate to each other[10]. And, then there are Black Swan technologies/events - outliers which have an extreme impact, and retrospective predictability[11]. A Black Swan points to the occurrence of a rare and unpredictable event challenging long-standing premises, causing disruption, and leading to transformation. In his New York Times best-selling book, “The Black Swan”, author Nassim Nicholas Taleb[11] claims that our world is dominated by black swans, and even as rare as they occur, they lead to all major scientific discoveries, historical events, and artistic accomplishments. He cites the example of the three recent technological inventions that most impact our world today - the internet, the computer, and the laser - and notes that all three were unplanned, unpredicted, and remained surprisingly unappreciated well after their discovery, before taking the world by storm.

It is fair to assume that we don't know yet how the Fourth Industrial Revolution and the fusion of yet-to-be unleashed technologies will play out but as rightly noted by Taleb, "the response to it must be integrated and comprehensive, involving all stakeholders of the global polity, from the public and private sectors to academia and civil society."

In academia, as owners of the curriculum, we must retool our curriculum to prepare our students not only to the know-how of the current and new technologies on the horizon but we must also train them to be nimble and alert to the disruptive innovation-the Black Swan innovation.

3. Humanistic component

As in the past, our tool box of technologies-- current and emerging --holds promise for providing solutions to our on-going and on-the-horizon problems. However, we have to be cognizant that large scale applications of technical solutions may bring about unintended consequences whose impact may be as grave as the problems they were meant to solve. A series of errors and potential disasters (DDT, genetically modified crops, Chernobyl), all associated with new technologies, has undermined the confidence of public in the power of technologies to solve problems and improve their quality of life[12]. There is also a perception that technology is "out of control" and that, too often, societies do not have the ability to orchestrate a responsible development of powerful technologies that have the potential for huge economic development.

At the International Conference on Engineering Education held in Valencia, Italy, 2003, Fisher and Mahajan[13] noted that the increasing complexity of societal issues, environmental considerations, and technological progress means that engineers are being asked to make decisions that not only require technical expertise but also a keen understanding of broad, socio-humanistic contexts and considerations. They also made an observation that the engineering curriculum in most academic institutions is generally not geared towards integration of the technical course work with these socio-humanistic issues in any rational way. "There is clearly a need to rethink and reinvent the engineering curriculum so that it focuses on producing Humanistic Engineers who are able to initiate and engage in effective dialogue with non-technical audiences regarding socio-humanistic critiques of engineering processes and products and who are able to perform their own socio-humanistic critiques in the absence of such dialogue." Most of these considerations have been implicitly recognized by U.S. educational accreditation and governmental funding agencies for several years[14,15].

In 2017, these observations ring truer today. As technology and innovation continue to advance at faster rates than before, we need to insure that we train our students to address accompanying social and ethical issues such as the unequal distribution of benefits and unexpected extension use of technology beyond the original intent. The need for meaningful reform in the engineering curriculum is urgent.

4. Proposed curriculum for Bachelor's in Mechanical Engineering

In light of the arguments forwarded in the text above, I submit that we need to retool the engineering curriculum to become a resource for educating a new generation of engineers-The Next Great Generation, if I may dare say, who can become agents of change and developers of elegant solutions to a host of grand challenges facing humanity. We need 21st century renaissance engineers who not only have depth of knowledge in their respective disciplines, but who can also integrate technical and humanistic perspectives *in both directions* in a truly interdisciplinary fashion, drawing from innovative collaborations that reflect the continuous and interconnected fabric of the real world. We want our engineers to think beyond the incremental engineering improvements, dream “big” and reach for the Mars (!) and develop solutions to solve major problems facing humanity. It is time to stress the importance of taking our designs and solutions from the confines of the laboratories to the market place.

It is imperative that we as educators in academia imbue our engineering graduates with the missionary zeal to serve society at large and also give them the skill set necessary to live holistic and multidimensional personal lives.

With these guiding principles in mind, I have put together a curriculum for a four year Bachelor’s degree in Mechanical Engineering. It is a unique blend of human and social sciences, applied sciences, communication, entrepreneurship, and leadership besides the required math and core mechanical courses. In alignment with Robinson[16], the concepts of analogical thinking that includes descriptive case-based examples as source analogs for problem solving are included in one of the core courses on humanities and social sciences.

Special care has been taken to allow a student to pursue his/her interests within mechanical engineering from a broad range of technical electives and interests outside engineering using free electives. I feel this will enable an institution to produce quality mechanical engineers with a social conscience directed towards the uplifting of all the people. The sample curriculum, shown in the attached chart, uses Virginia Tech Mechanical Engineering Department’s current curriculum as a base. The curriculum has been developed in such a way so as to keep the first year of engineering common to most engineering branches. Semester 3 has only one core mechanical course, so the student really delves into mechanical engineering only in semester 4. I feel this allows a student to develop a broad base in different areas before specializing in his/her major field of study.

The “spiral method” of learning[17,18] has been proposed to be interwoven throughout the 4 years, wherein basics from a previous course are first revised before moving to more advanced concepts. Also home courses have been established for HSS 101 – Ethics, Sustainability and Rural Development; at least one in each semester wherein the basics learnt in HSS 101 are applied to specific cases related to the course. The relevant courses in the flowchart have been marked ‘**€ -** Home Course for HSS 101’.

A student will have to complete 130 credits to successfully complete the Bachelor’s degree. A break up of the credits according to semesters and area of courses for all the four years is given below:

SEM 1-8 TOTAL: 16 +14 + 17 + 18 + 14 + 17 + 18 + 16 = 130 CREDITS

Human and Social Science (HSS): 16 Credits

Communication: 6 credits

Applied science: 14 credits

Free electives: 9 credits

Technical electives: 12 credits

Core ME requirements: Math + statistics: 18; Engineering: 55

5. Concluding Remarks

We live in an era of rapid, human-driven change in which we face a number of major problems including meeting the basic needs of a growing global population without further degrading the environment. This is a gigantic task demanding of us- engineering educators- serious and immediate attention to training the next generation of engineers who can step up to the global challenges and provide leadership in creating innovative and sustainable solutions to a host of serious problems facing humanity. We need to train the next generation of engineers who can measure up to this challenge, and who are ready to seize opportunities to help solve important societal problems in holistic and meaningful ways. To this end, the current curriculum in various engineering disciplines needs to move beyond conventional silo-based contents to a high-impact program integrating interdisciplinary inquiry into the core courses and preparing students for multi-disciplinary local and global collaborations among government, industry, non-profits, and philanthropists. The retooled curriculum should capture the public imagination and increase support for public policies that foster science, technology, and innovation, and inspire the next generation of engineers- the 21st Century Humanistic Engineers.

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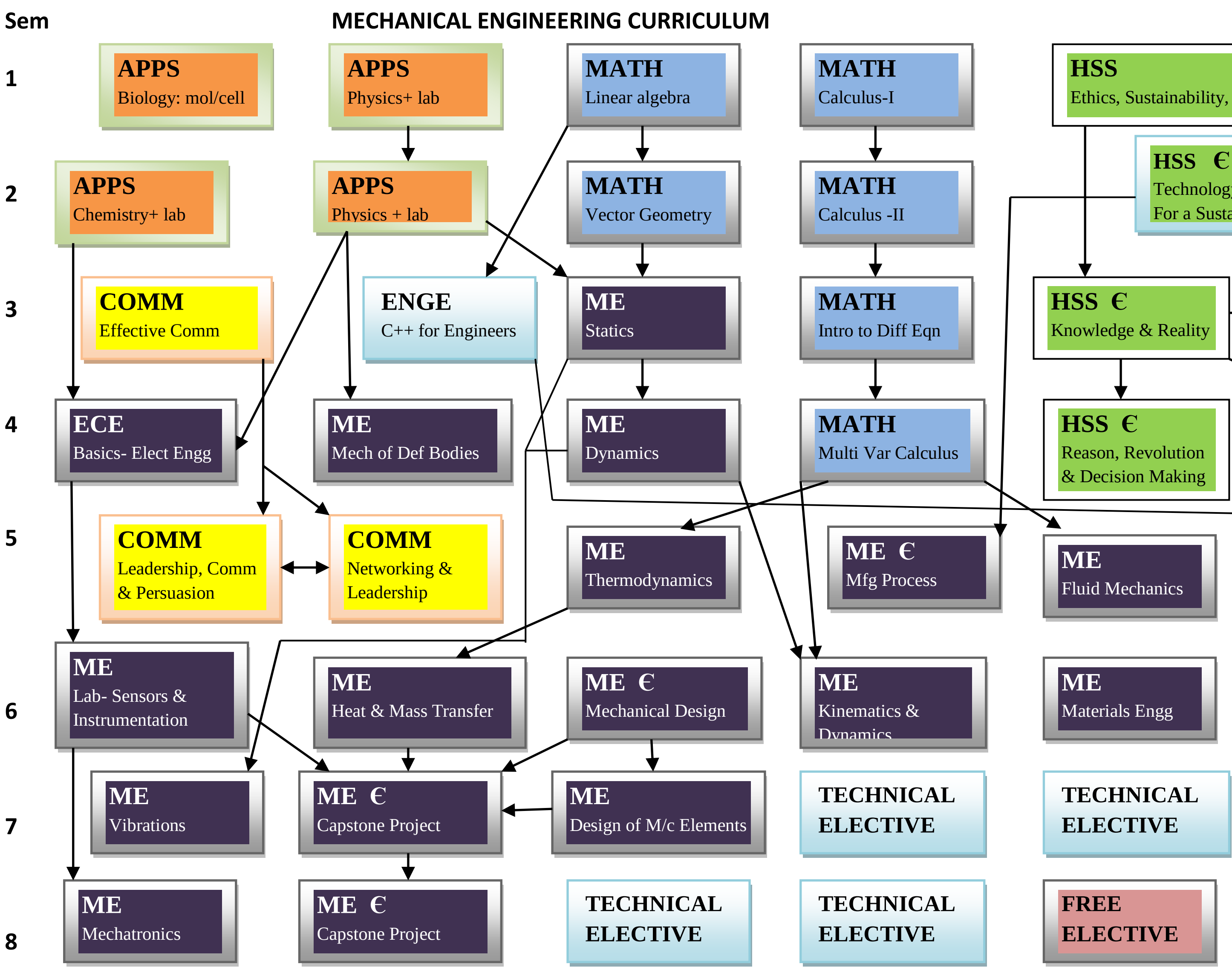
Name of the paper’s first author: Roop L. Mahajan

Brief Bio

Dr. Roop L. Mahajan is Lewis A. Hester Chair Professor of Mechanical Engineering at Virginia Tech, where since 2006; he has concurrently served as Executive Director of the Virginia Tech’s Institute for Critical Technology and Applied Science. Before joining Virginia Tech, he spent fifteen years at the University of Colorado at Boulder as Chair Professor of Mechanical Engineering, and fifteen 15 years prior to that at the AT&T Bell Laboratories Engineering Research Center, Princeton, NJ, as a Member Research Staff, a Research Leader and a Bell Labs Fellow. His research interests are Thermal Sciences, Nanotechnology, Biomedical devices, and Humanistic Engineering. He is a prolific researcher and has over 200 archival publications, several review articles, book chapters and a text book to his credit. Dr. Mahajan has won many awards he over the years for his research and leadership. Mahajan received his Ph.D. degree in Mechanical Engineering from Cornell University, Ithaca, NY, in 1977.


Sem
MECHANICAL ENGINEERING CURRICULUM
1
APPS Biology: mol/cell
APPS Physics+ lab
MATH Linear algebra
MATH Calculus-I
HSS Ethics, Sustainability,
2
APPS Chemistry+ lab
APPS Physics + lab
MATH Vector Geometry
MATH Calculus -II
HSS € Technolog For a Susta
3
COMM Effective Comm
ENGE C++ for Engineers
ME Statics
MATH Intro to Diff Eqn
HSS € Knowledge & Reality
4
ECE Basics- Elect Engg
ME Mech of Def Bodies
ME Dynamics
MATH Multi Var Calculus
HSS € Reason, Revolution & Decision Making
5
COMM Leadership, Comm & Persuasion
COMM Networking & Leadership
ME Thermodynamics
ME € Mfg Process
ME Fluid Mechanics
6
ME Lab- Sensors & Instrumentation
ME Heat & Mass Transfer
ME € Mechanical Design
ME Kinematics & Dynamics
ME Materials Engg
7
ME Vibrations
ME € Capstone Project
ME Design of M/c Elements
TECHNICAL ELECTIVE
TECHNICAL ELECTIVE
8
ME Mechatronics
ME € Capstone Project
TECHNICAL ELECTIVE
TECHNICAL ELECTIVE
FREE ELECTIVE