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Keynote Paper

PARADIGM SHIFT IN ENGINEERING EDUCATION IN THIS MILLENIUM

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1. INTRODUCTION

The engineers – the moulders of the physical world around us- has caused a phenomenal growth of our civilization, specially during the two or three decades of the twentieth century. It is predicted that the first century of this millenium will experience even faster rate of growth, which will be forged and shaped, amongst others, specially by factors :

1. The phenomenal growth of technology
2. The information technology (IT)
3. The Depletion of World's natural resources
4. The Environment and the sustainable development initiated by the Montreal Protocol
5. Fusion as well as osmosis of different conventional fields of engineering and other professions
6. The Globalization of economic activities
7. The Role of Government as Regulator and Monitor of development activities
8. The Human rights
9. The Paradigm shift in management of economic activities from the conventional system to the flexible knowledge based system

1.1 The phenomenal growth of technology

The industrial revolution started with the introduction of James' steam engines. Later the electric motors replaced the steam engines. American Ford introduced automatic machines (hard automation) to reduce the cost of production, but at the cost of mass production and of economy of scope. Though the mass production dominated the engineering profession over centuries, the consumer behavior changed radically over the last few decades and changed to more and more customization. For example, up to 1960s, Volkswagon car had a long product life cycle. Now the automobile companies are marketing cars with theoretically infinite combinations of customer choice on colour, steel/Aluminum wheel, power/conventional steering, manual/power windows, manual/power mirrors, 2-6 speakers stereo sound system, with/without GPS and so on. In the Hi-Tech sector American and Japanese companies were, as in 1997, marketing a new computer model in every 1.7years. Thus engineering organization are moving more and more towards the incremental and the fusion innovation rather than the break through innovation. Hard automation is now making way to soft automation achieved through computerization. Kennedy writes (Kennedy, 1993): Perhaps the famous FANUC manufacturing plant near Mount Fuji comes closest to representing the factory of the future. Before 1982 a work force of 108 people and 32 robots produced about 6000 spindle motors and servo-motors each month. After a radical redesign and further automation of the factory, it now employs only 60 people and has 101 robots to produce 10,000 servo- motors a month - a three-fold improvement in productivity. Nissan motors was spending 11 months and ¥ 4 billion to organise and set up the body assembly of anew car model. With soft automation the time is now a quarter and the cost is about one-third (The Economist, 1990).

1.2 The phenomenal growth of Electronics and Information Technology (IT)

The rate of diffusion of IT in a modern society – irrespective of the developed and the developing – is remarkably high. For example, it took 76 years of the Japanese telephone sector to reach 10% household diffusion rate, while the Internet reached the same level in only 5 years (Negoro, 2000).

Information technology has brought forth a new economics through the 'reach' and the 'richness' of information (Evans and Wuster, 1997). What I said earlier (Azim, 2000), IT has made it possible for a producer of goods and services to 'reach', by the click of mouse, millions of customers all over the world with detailed ('rich') information on his produce. Mass media like TV, newspapers have perhaps similar reach, but not so rich and are much more expensive. On the other hand, a salesman can provide 'rich' (detailed) information about (a) product to individual customer(s), but cannot 'reach' hundreds and thousands of customers all over the world at the same time.

Tele-work, Tele-shopping, Tele-design etc. through networked computers will result in the reduced size of the conventional organisation, reduced demand on transportation, reduced size of the office building, affect

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urban and countryside life and engulf almost all fields of engineering. During the International Conference on knowledge Transfer, KT-96 in London we predicted (Azim, 1996) that the virtual university is in the offing. Virtual libraries will replace present-day libraries. The access to the Internet and other networks will be faster, cheaper and more easily accessible in the coming decades. An engineering student from any country-developing or developed- may then register Basic Electronics course with a Professor at MIT, Industrial Electronics with a Professor at the Technical University of Berlin, Robotics at Tokyo University, Engineering Economics in U.K. and so on.

1.3 Natural Resources Limitation (Of The Earth)

Along with the exorbitantly high per capita consumption of material resources by the industrialized countries, their demand in the developing countries is increasing rapidly. But our Earth has fixed natural resources' reserve. This will consequently demand from the engineers a higher material productivity, material recycling, search for new alternative materials and search for new sources of materials.

With the use of high capacity computers and advanced software it is now possible to design a part with lower factor of safety acheiving higher material productivity. In building and automobile industry steel and timber are being replaced by aluminum and plastics. This has again a snow-boll effect. An average American car weighs 2800 lbs., but by using aluminum alloy, the weight is reduced to 2000 lbs. (a 40% weight saving). The use of plastics has reduced the weight and the power demand, so that 15 HP engine can run a car consuming a gallon of fuel for 90 miles.

1.4 The Environment and the Sustainable Development

Technology- and energy-intensive development is having its toll on earth's environment. CFCs liberated by engineering products like refrigeration and air-conditioning plants and aerosols and processes like cleaning of micro-chips are destroying earth's ozone shield exposing us to the ultra-violet ray of the sun.

Carbon-dioxide from power plants, engines and industrial plant is causing green house effect. Acid rain and smog are mostly due to engineering activities. Hence we have to redefine productivity in terms of green productivity.

Young engineering students have to be taught about the menace of waste plastics and how to recycle them by reuse. NKK corporation of Japan is using, since October 1996, waste plastics (excluding PVC) as a reducing agent in its blast furnace (Koichi, 1997). This may, when run commercially, recycle app. 800,000 tons of plastics annually. A steelwork near Bremen, Germany is using a similar technology in its blast furnace. Fuji Recycle constructed in 1994 a commercial petrifaction plant, which recycles plastics into naphtha and LPG, subsequently naphtha into gasoline, kerosene and light oil. Coca-Cola Co. and Pepsi Cola Co. of USA are chemically resolving PET bottles into telephthalic acid and ethylene glycol for reuse.

2. ENGINEERING IS NOT IVORY TOWER

The engineers may build a tower of ivory. But engineering is not ivory tower. Mainly due to the factors mentioned in section 1, a trend has already been set for a paradigm shift in engineering profession for the last three or more decades. Whether it is a power plant, a building, a fertilizer or an electrical machine, the ultimate objective is its acceptability in the market - which is now global, i.e. global consumer satisfaction. Gone are the days of colonial hegemony, the adoration of the country of origin of a product (e.g. made in England). Companies are busy in Brand building. Intel Inside is a glaring example.

The concept of vertical integration – for example, owning of mines to the production of steel to ship building is out-of-context now. The horizontal integration of R & D, procurement, manufacturing and marketing has been set forth. I have discussed this more in details earlier (Azim, 2001). The paradigm shift lies in the horizontal spread of engineering profession, which starts with the generation of the idea of an engineering product ending up in its marketing, maintenance and substitution.

3. NEW PARADIGM OF KNOWLEDGE BASE IN ENGINEERING PROFESSION

Engineering Knowledge domain has undergone marked shift. The tremendous knowledge explosion in the conventional engineering fields like Civil, Mechanical or Electrical engineering, has disintegrated each of them into independent specialized knowledge domain. This process will be termed **Knowledge Differentiation**. The last two decades or so have experienced a so-far-unseen fusion and osmosis of one engineering field with another. This process has led to new areas of engineering profession and will be termed **Knowledge Integration**.

3.1 Knowledge Differentiation

The Society of Manufacturing Engineers (of USA) has identified 11 manufacturing related specialized areas. They are:

1. The Computer and Automated Systems
2. Composite Manufacturing
3. Electronics manufacturing
4. Finishing Processes
5. Machine Vision
6. Machining Technology
7. Manufacturing Research
8. Forming and Fabrication Technologies
9. The Plastic Moulding
10. Rapid Prototyping
11. Robotics.

Specialization is attained in one of these new fields and accordingly specialized journals are being published. Such knowledge differentiation can be cited for every conventional engineering field.

3.2 Knowledge Integration

The present day automobile engineering is significantly different. A growing range of disciplines like material science (body fabrication and coating, wheels, inner gazettes, upholstery etc.), electricity (for power and lighting), telecommunication (for GPS), electronics (for EFI, speed and temperature control), air-conditioning, fluid mechanics (for air circulation), ergonomics (for the driver) and environment have merged together.

Various degrees of osmosis of conventional engineering topics, chemistry, economics etc. have taken place in the **Environmental Engineering**.

The development of **ceramics technology** – a fusion of manufacturing, materials and chemical engineering will lead to revolutionary changes in the field of IC engines.

Bio-medical engineering is developed through the integration of computer engineering, ophthalmology and biology. Neumorphic vision chips will adapt in milliseconds to vast changes in illumination.

The intelligent garments sector integrates garments technology with the telecommunication technology.

3.3 The Dynamics in Engineering Profession

Due to this new paradigm in knowledge base in engineering profession caused by the knowledge differentiation and the knowledge integration, an engineer has to change the profession 3-5 times in his economic life of 30-40 years. The engineering students have to be trained about this new dynamics of engineering profession. **Continuing Professional Development** has become a must.

4. FORMAL KNOWLEDGE DELIVERY AT ENGINEERING UNDERGRADUATE LEVEL KNOWLEDGE

The paradigm shift in the statics and the dynamics of engineering profession, caused by knowledge differentiation and knowledge integration, is baffling the engineering educators. The knowledge that has to be delivered during the undergraduate study has increased tremendously. Though some institutions are offering 5-year degree program, most of the undergraduate studies in engineering are for four years, raising the rate of knowledge delivery accordingly. One good news is that in developing countries like Bangladesh the knowledge of quantum at the pre-university science education has been recently raised. Engineering educators should seize this opportunity to reorganise the courses and the curricula.

At the same time the productivity of knowledge dissemination can be increased through fusion of contents of different courses. For example, while teaching the students integral calculus, the area moment of inertia can be taught.

Furthermore, a student receives his knowledge of engineering from six different sources (Fig. 1). Though all the sources play prominent role in the developed countries, only three factors (teacher, textbook and laboratory) are important in the developing countries. Again, available textbooks and the laboratory equipment are quite old. Thus the knowledge delivery in engineering education is primarily dependent on the teacher.

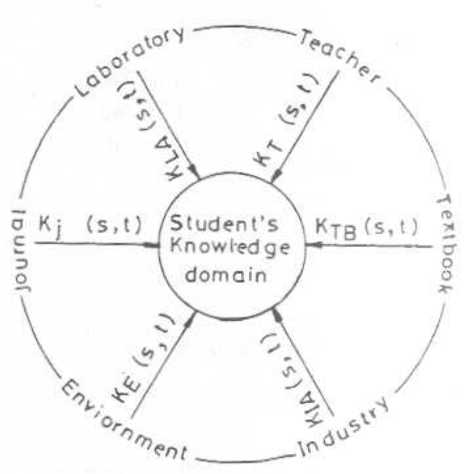

Fig. 1 Knowledge sources of an engineering student

Added to this, there is a great disparity between the demand and the supply in engineering education in the developing countries. As a result of discussions in the last paragraph, the source of an engineering student's knowledge domain is primarily software based; while the demand on him at his workplace is predominantly based on the hardware available at the workplace. This is a great challenge to the engineering education in the developing countries.

The engineering educators and planners have to face these multi-dimensional problems of engineering education squarely. In doing so, we can at the outset divide the knowledge delivered into 4 categories:

Core Science:
Mathematics, Physics, Chemistry, Material Science ….

Core Engineering:
Applied Mechanics, Fluid Mechanics, Mechanics of materials, Thermodynamics, Computation, Electronics ……

Specific Specialization:
Manufacturing Process, Machine Tools, Heat Engines, Air-conditioning, Fluid Machinery, Power Plant Engineering, Environmental Engineering ……

Social Science:
Communication,Economics,Accountancy,Law,Management, Environment …….

Quite evidently, the objective of the core science and the core engineering courses is to equip the student with the science and the engineering background and to develop his thinking process to understand the basics of engineering, on which he builds up his engineering specialization.

An engineering student develops his in-depth specialization and know-how in different fields of engineering with the help of specific specialization courses. Social science courses enhance his communication skill and the capability to manage the affairs of an engineering organization in an effective and competitive manner.

Because the modern world economy is shaped by the rapid technological development, controlled by the canons of globalization and driven more by the capitalistic system, the expertise of a fresh engineering graduate should be developed in this perspective. For example, an automobile engineer specializing in mechanical engineering drives and controls can hardly be called a specialist of automobiles using electronics, pneumatic and hydraulic systems and regulated by the laws of environment. If his knowledge base was enriched with the courses on like electronics, fluid mechanics, environment, he can adapt himself with the modern development in automobile engineering and remain an expert in the gradually shifting domain of automobile engineering.

Having said so, the areas of the core science, the core engineering and the social science have to be given more weight than the area of the specific specialization. Early 1990s The Institution of Engineers, Australia demanded from the universities in Australia to increase the contact hours of management courses in engineering undergraduate curriculum, which they obliged without much delay. The following table compares two representative universities - one from the developed economy and the other from the developing one.

Table 1: Comparison of weight given to the four areas of knowledge delivery

	University of a developed country (Manufacturing Engineering) %	University of a developing country (different disciplines) %
Core Science	23.8	15 – 23
Core Engineering	22.6	21.8 – 30
Specific Specialization	23.8	37.5 – 48
Social Science	29.8	9.5 – 13.1

The comparison depicts that the university of a developing country gives much more stress on specific specialization at the cost of the social science. In Bangladesh we have a common say that engineers are not good managers and communicators. The table also reflects the same thing.

Furthermore, most of the universities are awarding an engineering under-graduate degree after the successful completion of 120 credits. If the requirement is increased to, say, 160 credits (190-200 contact hours), the students have less time for analysis, comprehension and synthesis. They may tend to become more mechanical in solving problems, rather than being innovative and rationally understanding. One way to reduce the credits is to reduce the course content through the fusion approach (Azim, 1996). The other approach may be to introduce an effective industrial attachment, where a major part of the theoretical lectures can be supplemented by the practical applications, reducing the need for the laboratory courses. All these will demand a clinical restructuring of engineering education system.

5. CONCLUSION

This millenium will experience a tremendous explosion of engineering knowledge domain, knowledge differentiation and knowledge integration with the emergence of new professions, which will be gradually substituted by newer professions. To cope up with these challenges there has to be a paradigm shift in engineering education system. The engineering education in the next few decades should aim at:

1. Generating flexible engineers. They should be well-trained in a. basic science, b. core engineering and c. social science. They should be innovative, flexible to adapt to the changes in the profession and solve problems optimally.
2. Offering specific specialization after the graduation.
3. Flexible knowledge delivery. Instead of being time-and space-dependent knowledge delivery, it should be rather time-and space-independent. Networked computers and multi-media communication may radically change the education infrastructure in the next few decades.
4. Improving the communication and the management capability of the graduates, who should have also good command on global/regional languages.

The universities in the developing countries should:

5. Reduce the credit requirement significantly.
6. Increase the cooperation between the academia and the praxis
   - through, for example, adjunct faculty from the industry
   - by including an effective industrial attachment for the students.
7. Go for the accreditation of their programms.
8. Computer literacy should be a pre-requisite for the entry into the engineering education.

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