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The Educational Process

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This paper considers the underlying rationale in designing an engineering educational programme, the basic objectives that should be addressed, the methodology employed, the levels of engineering specialisation and the pedagogy for transferring engineering knowledge.

INTRODUCTION

Engineering is a unique profession since it is inherently connected to providing solutions to some expressed demand of society with heavy emphasis on exploiting scientific knowledge. Beginning with ancient construction and military demands, engineering evolved to encompass and drive the industrial growth of the modern technological society. Such modern technological societies have multifaceted engineering demands to address problems associated with the environment, health and safety issues, energy, communications, economic development, recreation, etc. Two hundred years ago, Thomas Jefferson succinctly captured its essence when he wrote, *the main goal of science and its applications is the betterment of society*.

The following considers the underlying rationale in designing an engineering educational programme, the basic objectives that should be addressed, the methodology employed, levels of engineering specialisation and the pedagogy for transferring engineering knowledge.

DESIGNING A PROGRAMME

Inherent to the design of an engineering programme is the basic issues that a society wishes to be addressed. These issues are normally defined through the nation's political process. For example, in an undeveloped country this could be to provide a basic technology application capability in an agrarian society, or in a developing country to expand to a more advance technological base. Depending on the societal objectives, specific focus areas, such as electronics, energy utilisation, civil infrastructure, various types of manufacturing, transportation, communications, etc, may be elected. It is also useful to speculate on those engineering advances and technologies that will evolve in the next decade: what type of knowledge and background is needed to develop the engineering expertise to achieve these technological advances useful to the society?

Defining an engineering programme is also related to political and economic questions associated with the size of the target group of students. With ever increasing competition through secondary education and admission examinations, it is possible to identify a limited number of technically gifted individuals to attend relatively small engineering colleges (eg the French Grande Ecole model). Alternately, a much broader egalitarian model is possible where all who can achieve a given admission standard have an opportunity to study engineering (eg the United States public university model). While, in either case, a society's political process will define which approach it follows, sufficient resources are required to ensure a quality, engineering education programme. These resources include quality faculty, motivated students and modern physical facilities, which include laboratories, instrumentation and computer access to the Internet.

Once the general educational philosophy is defined, the engineering discipline foci required to address a society's goals must be identified. Historically, the four disciplines that provide the intellectual basis for other specialisations are Electrical, Mechanical, Civil and Chemical Engineering. Computer Science and Engineering are more recent main line engineering programmes that also are intrinsic parts of the other four.

In summary, defining an engineering programme requires:

- Identification of societal issues to be addressed.

- Defining the size of the target student body.
- Establishing engineering focus areas of study.
- Establishing resources required for the above.

BASIC OBJECTIVES

Inherent to engineering education is the historical base of physics, chemistry and mathematics, which has formed the base for all disciplinary specialisations of engineering and the tremendous advances that engineering and technology have made over the last century. However, it is expected that molecular and microbiology will become an additional required part of the educational base of engineers in the near future. A basic objective of an engineering programme is to provide the individual with a firm foundation in these natural sciences from which to build technological applications.

It cannot be emphasised strongly enough that engineering is *NOT* just an extension of the basic sciences. Rather, engineering exploits these fundamental sciences, integrating them with sufficient business and economic considerations into practical applications. Depending upon the desired application, engineering can exploit the most advanced aspects of the basic sciences or the more routine and well-understood aspects. It is not the level of sophistication of the science used that differentiates the engineer from the scientist, but rather the goal of a specific application. Ultimately, the value of the engineer is developing and implementing technical applications for the improvement of society.

METHODOLOGY

The developed world has generated numerous reports on specific subject material that should be included in curricula for various engineering disciplines. While the distribution and amount of specific subjects covered in a curriculum vary depending upon local circumstances, they all encompass a firm understanding of the basic sciences and mathematics (through partial differential equations and linear algebra), economics, ethics, the engineering sciences and a concerted effort to integrate these subjects. The emphasis is on synthesis and the development of the student engineer to become increasingly skilful in obtaining solutions to open-ended problems. They must develop the *know-how* to estimate the influence of factors for which little or no information or data is available. A successful curriculum distributes such synthesis throughout the length of the programme to reinforce the development of this capability.

In addition to this more formal knowledge base, practical *know-how* must also be developed. While all fields benefit from an individual's experience, engineering is especially impacted by it. Exposure to applications in related fields often translates into *innovations* in different fields. Hence the need for engineers to be committed to life-long learning and continued expansion of their personal knowledge base. The result of applying one's engineering expertise leads to the development of a good, physical understanding regarding how technical devices, components, etc will function. Such *field experience* provides the basis for successful, intuitive extrapolation in engineering judgements.

There is an additional strong element in engineering education: the human dimension. Since the ultimate fruit of engineering is a technological application for use by society, an important aspect of an engineer's education is directly related to safety: inherent safety of a design, inherent safety of the manufacturing process, and inherent safety of its ultimate use. Related professional ethical considerations should instill in the engineers the requirement not to compromise on this issue.

The methodology of engineering is to develop models to predict characteristics of specific designs, whether these are components or complete assemblies. While not inclusive of all influences, it is the job of engineers to ensure that major influences and effects are incorporated in these engineering models. This is also an instance where *field experience* becomes important to ensure that major influences and effects are incorporated. Computer modelling increasingly allows us to incorporate more and more technical aspects that are needed for these engineering models. However, technical aspects that are insufficiently understood must be addressed through empirical correlations over the proposed range of variables. Such empirical correlations can be incorporated into these models through laboratory studies. The resulting engineering models then permit a wide range of designs to be evaluated for performance suitability and manufacturability. This reduces the number of possible solutions and prototypes that need to be built for testing. Completely analogous to this design process is the development of engineering models for manufacturing processes. Such modelling can significantly reduce the time to develop and manufacture a new product.

Modern technological advances permit ever increasingly sophisticated models and evaluation procedures. For example, three-dimensional virtual computer environments are permitting the evaluation of components and complete assemblies, visualisation of dynamic response, visualisation of air flow and energy distribution, evaluation of manufacturing processes, simulation of complete devices, etc. In fact, the intensive growth of computer simulation to all aspects of engineering gives rise to the concept of incorporating the basic ideas of such simulations into a *simulation science*. It should be stressed that computer simulations are only as good as our understanding of the underlying sciences.

LEVEL OF SPECIALISATIONS

Throughout the developed nations, engineering education is divided into basic engineering programmes that address specific disciplines, and advanced engineering programmes with significantly more in-depth studies in specialised areas. In Europe the former is characterised by five years of studies (eg the Italian Laureate, French Grande Ecoles programme) and the latter by doctoral programmes. In the US and British Commonwealth the former is characterised by four year programmes (Baccalaureates) and the latter by two degrees, a Master's of Science or Engineering of one to two years duration followed by more intensive doctoral studies.

With the rapid globalisation of the economics of nations and the growth of multinational corporations, the engineering professional will increasingly hold positions which cross national boundaries. Engineering accreditation groups (eg ABET) are attempting to define *equivalency* between national models. It will have a definite impact on establishing common national licensing requirements by defining standards of quality for engineering educational programmes.

Within the basic and advanced engineering programmes are various specific disciplines. The basic disciplines include Electrical, Mechanical, Civil and Chemical Engineering. Most others are sub-specialties of these (eg Aerospace, Applied Mechanics, Industrial, Environmental, etc). Two new areas that will be future major engineering disciplines are Bioengineering and Computer Science and Engineering.

It should be noted that increasingly more in-depth technical knowledge is required at all engineering levels, while, simultaneously, cross-disciplinary demands required of modern needs are growing exponentially.

Another noteworthy item is the growing importance of molecular and non-equilibrium processes in all aspects of engineering. For example, these are of major importance for applications in surface modifications, material processing, electronics, environmental control, energy efficiency, tribology, bio-processing, etc. Miniaturisation is also impacting all disciplines of engineering. Micro- and nano-electromechanical systems, micro- and nano-fabrication, and micro- and nano- assembly potentially may have as large an impact as computers in technical applications. New phenomena are being observed at the parametric extremes of traditional disciplines that are leading to whole new fields of applications. Similarly, the interfaces between disciplines are providing new approaches to deal with entire classes of technical problems and are creating new products and industries.

These latter comments are meant to illustrate the dynamic nature of engineering and hence the required associated dynamic nature of the engineering educational process. The levels of specialisations are not static, but rather ever expanding. To provide a quality educational process requires a commitment from the faculty to maintain their expertise at the forefront of their profession, either through their own relevant research or continuing self-education of technological advancements. It is also a function of the institution to assist the faculty to maintain their professional competency. If this is not done, it will adversely impact the process of educating future engineers.

THE PEDAGOGY

Historically, the main pedagogy centred around formal and informal lectures by highly qualified faculty. These could be small or large classes wherein the faculty member attempts to explain technical concepts and procedures. Frequent, required, external class assignments and examinations provide the instructor with a feedback mechanism to evaluate how well the material is grasped and understood by the students. When areas of poor understanding are noted, the faculty member can initiate individual and or group remedial instruction.

Laboratory instruction is often a complement to the lectures for developing hands-on experience with the physical concepts explained in lectures. The laboratory experiences also provide training in the proper use of a variety of diagnostic instrumentation and experimental protocols, statistical design of experiments and evaluation of experimental data reduction and data accuracy. These are all areas that must be understood by the engineer.

Integration of sufficient laboratory and lecture goals provides the student with the basic intellectual tools and skills required.

In recent years, modifications to the historical lecture format have been implemented with significant success. Rather than long lectures, shorter overviews of a topic are presented, followed by extensive use of educational software wherein the student can explore various aspects of the short lecture and *discover* the details of a subject by themselves. Under this format, after the short lecture the professor acts as a guide, answers questions and is a general resource for the subject material. The concept is that the student learns more thoroughly with such personal involvement.

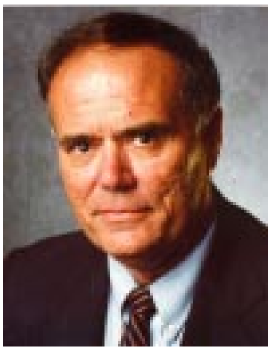
Over the last few years, the lecture format also has been significantly enhanced by incorporating into engineering courses extensive integration of our increasing computational capabilities and by educational modules via the Internet. The extensive integration of computational capabilities into engineering courses has permitted a number of educational enhancements. The first enhancement involved significant increases in the range of parametric variations that are possible to demonstrate in courses. Computers make feasible extensive use of *what if* scenarios. Students can self-evaluate how changing the magnitude of the parameters in engineering models or designs can significantly alter the predicted outcome. Used properly, this approach permits the student to develop a physical feel for various types of problems and hence some engineering experience as part of their educational process. It has proven to be an invaluable enhancement in modern engineering education.

The second development employs the use of web-based information and modules on the Internet. Extensive information and data can easily be obtained for a variety of real world problems from the web that can expand the in-depth education of the student engineer. This ability to extract extensive information and data via the web has become a mandatory capability for engineering students that they will utilise throughout their professional careers. The more recent development of educational modules by various faculty members for use over the Internet is growing rapidly. These modules permit a wide variety of instructional enhancements, ranging from computational procedures and experiments to the visualisation of various physical phenomena. For example, in the study of antenna theory in electrodynamics, the three-dimensional radiation lobes can be visualised. In this case, the student can modify the phase angles and amplitudes and physically observe the resulting antenna performance. They can rotate the visualisation to examine its three-dimensional characteristics. Similarly in fluid dynamics, the visualisation of shock wave phenomena can show the influence of various flow parameters. Other examples involving modules and visualising various types of dynamic response, etc are available.

A more recent Internet enhancement combines lectures, modules and information retrieval between two or more class sites together with technical *chat rooms*. Registered students can exchange information, raise common questions and provide common discussion of class related material. This provides an additional avenue for the development of the technical expertise of engineering students, and also offers the possibility for shared course responsibility by faculty at one or multiple institutions. Internet access is thus becoming a necessary requirement in modern engineering education.

The forgoing educational approach further emphasises the nature of engineering, eg individual capabilities and expertise integrated into group efforts. Such efforts involve interactive solution and approaches to practical problems. Inherent to the engineer's formal education process is the goal to develop the individual's expertise, develop a functional ability for group effort and to develop a focus towards practical applications. This is normally accomplished through the challenge of a variety of *design problems* interspersed throughout the formal curriculum.

BIOGRAPHY



Dr Lawrence A. Kennedy is Dean and Professor of Mechanical and Chemical Engineering at the University of Illinois at Chicago. Prior to joining UIC in 1995 he was the Ralph W. Kurtz Distinguished Professor of Mechanical Engineering at the Ohio State University (OSU). During the period 1983-1993 he served as Chairman of the OSU's Department of Mechanical Engineering and guided the significant growth of the Department's academic and research programmes. He was named the Ralph W. Kurtz Distinguished Professor in 1992. He also served as Acting Director of the Center for Automotive Research and was a professor at the Ohio Aerospace Institute at NASA Lewis Research Center. Prior to joining Ohio State he was on the faculty of the State University of New York Buffalo. He has been a visiting professor at Princeton University, the University of Michigan, the Von Karman Institute of Fluid Dynamics, and the University of California/San Diego. Professor Kennedy received his MS and PhD degrees from Northwestern University and his BS degree (cum laude honors) from the University of Detroit.

Professor Kennedy's technical interests include the broad areas of combustion, non-equilibrium processes, emissions, fluid and thermal sciences. Research projects have involved the following topics: super-adiabatic filtration combustion; non-equilibrium processes, optical diagnostics; combustion environmental control, continuous and unsteady combustion processes, design problems associated with combustion, environmental and energy transfer systems. He has over 120 journal publications and more than 150 other scientific publications.