TRENDS IN MECHANICAL ENGINEERING EDUCATION: THE INTERNATIONAL SCENARIO AND ITS RELEVANCE TO SRI LANKA

J.S. Gunasekera
Moss Professor & Chairman, Department of Mechanical Engineering
Ohio University, USA

ABSTRACT:

Mechanical Engineering Education has undergone major changes during the last few decades in most countries throughout the world but particularly so in the US and Europe. These include: the strong emphasis on engineering design, integrated throughout the curriculum; the need to connect and integrate contiguous ME disciplines together to form a more robust engineering science foundation; and the critical role that a senior level "capstone" product realization course should play in broadening students' understanding of engineering practice. There is also strong support for increasing emphasis on "active learning" where students participate more directly in the learning process and the important role played by "cooperative education" as referred to, in the US. It is important for Mechanical Engineering departments in Sri Lanka to take a closer look at these changes, and adapt them to enhance their own curricula by carefully noticing that what is best for other countries may not be the best for Sri Lanka.

1. INTRODUCTION

The future of Sri Lanka will strongly depend upon the quality of education and mechanical engineering education can be further improved by focusing on its educational mission and using better pedagogical tools. An enhanced education can be better achieved when educational institutions and industry join forces to work together for a common goal. There is a need for a common vision (as evidence by this conference) for engineering education in the 21st century. The method of realizing this vision may well change from institution to institution. There is also a need to develop diverse pedagogical paradigms that can be shared among all institutions and create a culture where teaching and learning occupy center stage at the faculties of engineering in Sri Lanka.

A workshop on "Mechanical Engineering Undergraduate Education for the Next Twenty five Years" was organized by the MIT a few years ago to bring together the major Mechanical Engineering Departments in the United States to discuss the future of Mechanical Engineering Undergraduate Education. The intention was to emphasize future needs and opportunities, taking a long-term perspective of 20-25 years. The workshop focused on what an undergraduate Mechanical Engineering Education should include and how best it can be taught. It had three primary objectives. The first was to collect and share information on the various efforts being made to improve undergraduate ME education and to establish benchmarks. The second was to develop a collective vision of the future of Mechanical Engineering Undergraduate Education through open discussions and deliberations. The third was to develop an agenda for future collective and collaborative actions. This paper summarizes some of the important findings at this workshop.

The idea of such a Workshop originated with Professor Nam Suh, Head of the Mechanical Engineering Department at M.I.T., as a way for M.I.T and other schools to share their plans and experiences in developing and implementing new undergraduate M.E. curricula.

About 70 people participated in the Workshop (including the author), representing some 34 different institutions. The program was about equally split between presentations from different M.E. department representatives on major curriculum initiative and promising new teaching initiatives, and breakout groups of about fifteen people which addressed critical curriculum and educational questions and issues. The components of their topic, what the most important issues were, and, where time allowed, making recommendations for moving forward. Each breakout group brought a summary back to the Workshop.

2. MAJOR CURRICULUM THEMES

In the area of curriculum, there were three clear themes in several different institutions' raw programs or program plans.

(a) The importance of engineering design, introduced early in the curriculum and integrated throughout the curriculum.

(b) An essential core component of the M.E. curriculum must be a strong foundation in the engineering sciences. Contiguous disciplinary areas, however, should be grouped together into "decisions" to make their connectedness clear and to emphasize how engineering practice integrates the various basic principles together in its application.

(c) A senior level "capstone" course focused on the product realization (sometimes called product engineering) process should be used to integrate engineering science, design, and manufacturing, with real-world engineering practice issues.

This emphasis on design has been building for some years. Several important issues are now being highlighted which will make its enhanced role in the undergraduate curriculum more effective. These are: the early introduction of a major design experience, a focus on the open-ended and iterative nature of the design process, embedding design into engineering science courses in a more integrated manner, regarding "design" as "design and manufacturing," the importance in the design process of effective communication of ideas and results, the opportunity to introduce team-based design tasks into the curriculum. It is also clear that this potential can only be realized if teachers from the engineering sciences, engineering applications, and design and manufacturing areas all participate in this thrust.

There was a strong commitment to retain and strengthen the engineering science foundation of undergraduate M.E. education. Most new programs are attempting to connect and integrate together related disciplinary areas into set of domains. The commonly proposed domains are: Mechanics and Materials; Systems, Dynamics, and Control. Thermal Fluids Sciences (Thermodynamics, Fluid Mechanics, and Heat Transfer); Design and Manufacturing. The advantages of such integration or grouping are many. Commonalties can be identified and emphasized, the natural sequencing of material in each domain is clearer, the cross disciplinary nature of engineering practice can be introduced, the opportunities for more realistic exercises and design problems/projects are increased. It is important that laboratories, projects, and hands-on experiences be well connected with and compliment this domain-based disciplinary core. An important need with this more integrated approach to these essential disciplinary areas is the educational "texts" and support materials that appropriately reflect this interdisciplinary connection and integration.

The emphasis on an integrated senior level course, focused on product realization (or product engineering) was the result of several perceived needs. First, the career path of many graduates will be into engineering practice, and that practice will increasingly require a breadth of knowledge about the process by which products are engineered, produced and marketed. Second, the technical breadth and sophistication of engineering products is steadily increasing and analysis-based engineering is viewed as the most effective way to meet such requirements. Third, specific engineering tasks must be viewed in a broader context, and students should be introduced, as part of their undergraduate program, to this systems perspective which includes integrating elements of marketing, finance, management, and team experiences, with the technical aspects of design.

3. MAJOR EFFECTIVE TEACHING AND LEARNING THEMES

Many ideas, approaches, and methodologies were proposed at the Workshop for improving teaching. The breadth and creativity in these new approaches are substantial and very encouraging. They can be grouped around three major themes:

(a) Strong emphasis on "active learning," where students directly participate in as many aspects of their courses as is feasible.

(b) Use of a wide variety of learning experiences throughout the curriculum to provide students with a variety of contexts within which to learn, and provide multiple opportunities for students to invest strongly in their own education.

(c) Provide significant opportunities for students to assume greater responsibility for their education, and learn how to "learn on their own."

The first two themes have emerged from the realization that past teaching practices are too passive and restrictive for our future students and the evolving nature of engineering practice. Individual students learn in a variety of ways depending on their thought processes and interests. Providing students with many different types of opportunities to become much more actively involved in their courses is the obvious solution to this problem. Several ideas were suggested for doing this: for example,

- Embedding design activities in engineering science, as well as in design and manufacturing courses
- Using Industry initiated projects to provide real world experience
- Use of case studies to illustrate how technical and non-technical aspects of engineering combine
- Providing as much exposure to open-ended engineering problems as against fully defined problems
- Working in teams to both learn engineering as well as learn about team processes
- Use of self paced computer-based learning modules
- Use of the "studio format" to integrate across the conventional boundaries between lecture, recitation, design project and laboratory
- Use take home experiment kits to provide hands-on experiences and student generated data in engineering science courses
- With large classes, "break the lecture up" into shorter segments, each with its specific objective and different approach
- Use of demonstrations and simulations to promote learning through the explore, formalize, analysis cycle
- Use cooperative learning techniques--working in small groups on structured assignments--in large enrollment classes to engage students more directly as course material is developed
- Use short, intense, focused courses to develop student commitment, motivation and specific skills
- Use of reverse engineering (how does it work) exercises to promote independent inquiry
- Use of competitions--both larger and smaller scale--to promote student involvement in engineering science as well as design classes

Many of the above approaches also contribute to the third theme--encouraging students to assume greater responsibility for their education.

4. BREAKOUT GROUP CONCLUSIONS

Two breakout sessions were included in the Workshop, with different theme questions for each of the four groups in each session. Breakout group findings are summarized below under each theme question.

a). What are the essential components in the Mechanical Engineering undergraduate curriculum core?

There should be a strong emphasis on fundamental principles in the core. (Math, Physics, Chemistry, Computer Science & EE Courses part of the Mechanical Engineering core.) The major core domains are. (i) Mechanics & Materials; (ii) Theme Hard Sciences; (iii) Dynamics & Controls; (iv) Design & Manufacturing; (v) Laboratory Experiences; and (vi) Communication & Professional Practice.

b). How should the various components of the ME core be integrated?

<u>What is the purpose of integrating?</u> It provides context, promotes systems thinking, helps students retain what they have learned, it provides motivation, and is consistent with ME Department's Strategic Plans. There are however, reasons why it is difficult: There are teacher barriers (mindset, scheduling) and legitimate questions such as the value in seeing some topics in totality, and how much integration is desirable.

A number of ways to promote integration were suggested: use of a common engineering problem in several courses; guest lectures; theme-based projects/problems; (e.g., rate, momentum): connecting internships and co-ops; a project that comes through several courses; linked design activities, especially design projects, using topics like ethics to connect; integrating by means of the basic physics and math.

There are important questions to address, too. How can one know, if "it" works (need for assessment)? How can one integrate, across what breadth, and depth? How do teachers learn to teach in a more integrated course structure? How best to disseminate results? How can the department/faculty get teacher and resource support for integration? What is the role of cognitive science? How can a more integrated pedagogy with, rewards" (e.g.. grades) for students be achieved?

Here are the group's ideas for supporting integration: Labs (facilities, instrumentation), new teaching materials, strong administrative buy-in, programs for updating teaching skills, recognizing contributions in the reward system, collecting assessment evidence (ABET, tests, portfolios surveys, video evidence) on the question does it work? It is important to promote buy-in by other ME faculty and work on collaboration/integration with non-engineering and non-ME faculty as well. Departments should do 5 year plans, mission statements, etc. to work out how integration would support their long-term goals.

c). Engineering tools help students learn, and prepare them for engineering practice. What tools should be included in the undergraduate curriculum, and how?

The group developed a list of important tools to consider in the ME curriculum in these seven different areas: Visual representation, Analysis (Simulations), Communication, Information/Databases, Design/Synthesis, Manufacturing/ Prototyping, and Measurement/control/experiments.

The specific tools suggested in each category were:

(i) Visual representation: graphics/CAD, parametric CAD, sketching.

(ii) Analysis and Simulation: computational math packages, spreadsheets, FEM/CFD

(iii) Communication: web/internet, email, word-processing, presentation tools.

(iv) Information and Database: web, computer database packages on-line/office, libraries (physical).

(v) Design/Synthesis: optimization packages, decision analysis and statistics, creativity aids, conceptual design, axiomatic design.

(vi) Manufacturing/Prototyping: CNC, CAD/CAM, rapid prototyping, product realization.

(vii) Measurements/Control/Experiments: data acquisition equipment, sensors/actuators.

An important issue with many of these tools is whether the objective is for students to gain an awareness of the potential of each tool, and/or significant mastery or proficiency in their use.

d). Innovative and Effective Ways to "Teach" Mechanical Engineering Undergraduates

The rapid development of information based technologies is creating major challenges for educational institutions, posing the threat of significant dislocation. These challenges are: the changing (perhaps diminishing) role of universities; economically-driven replacement of faculty services by WWW delivery of instruction; concerns over the quality of information technology-based educational experiences (such as, superficiality of learning, replacement of reality (real vs. virtual), removal of opportunities for hard work (perspiration and failure); need to transcend WWW (will never be a "sole source" or "full service" medium). The opportunities are of course tremendous:

New Modes of Learning: student-centered and controlled; "scaffolding" of information and preparation; "cyber cafes" (connecting students with mentors; e.g., students with practicing engineers); self learning -computer tutors.

New Modes of Teaching: modularization (taking advantage of ready access to an abundance of materials to "tailor" and enrich courses; mentoring (both real time and asynchronous feedback to students); problem definition and refinement.

New Modes of Communication: enhancing the effectiveness of teams; distance learning opportunities.

Of course these opportunities raise important questions such as: Need for standardization, extensive (encyclopedic and interactive) educational modules, instruction on effective use, what Flexible/Agile educational delivery systems will work best to provide JIT Learning?

5. WHAT ROLES SHOULD LECTURES PLAY? WHAT MAKES GOOD LECTURES?

Lectures should inspire, motivate, and stimulate. They should clearly add value, develop insight and clarify complex concepts. They should augment and not duplicate the text. What makes good lectures? Lectures should actively involve all the students in the class. Instructors should be facilitators as well as teachers. Instructors should take responsibility for motivating students and should clearly identify learning objectives. Lectures are an appropriate format for developing linear material.

The key ingredients in using the "lecture format" successfully are: Having a knowledgeable faculty with enthusiasm and commitment to material and students, clear learning objectives, crisp presentation of fundamental principles, variety of delivery methods, spontaneity, and especially the active involvement of all students. Very important is making regular use of student feedback.

6. “HANDS ON” EXPERIENCES

The objectives of "hands-on experiences" are: exposure to "real world" situations to develop engineering judgment and enhance confidence; illustration i.e., demonstration of physical principles and comparison of reality with analysis; discovery, the development of basic skills, to motivate and involve students, and provide an appreciation of shop processes, their potential and their limitations; understanding of the integration process inherent in engineering, the engineering systems approach, physical realities, the need for life-long learning.

The group came up with the following hands-on experience methodologies (i) Projects, reverse engineering/build, junior/senior design/build/test; out-of-class examples are mini-baha race competitions, solar powered vehicle, human powered vehicle (ii) Laboratories, to provide exposure to instrumentation and techniques, to manufacturing tools, and to enliven the engine ring science part of the curriculum. (iii) Participatory activities such as in-class demonstration/illustrations, use of take home "kits" (e.g. Mary Boyce-MIT, Mechanics and Materials take-home kit). (iv) Co-op/intern opportunities, (v) Undergraduate research opportunities,

Several issues need to be thought through. Laboratory Format: should labs be directly associated with each lecture course or not? Should it formally use the explore, formulate, analyze (The Scientific Learning) Cycle? There are major resource concerns in the areas of equipment, personnel, and space. An important question is how much "hands-on" is appropriate, and how do we assess whether we have the right amount? There is a need for a repository of good ideas perhaps on the WWW And what about virtual "experiments"? These are legitimate educational tools, but they do not provide hands-on experiences.

7. CONCLUSIONS

There are significant changes taking place in Mechanical Engineering Education throughout the world. The new EC (Engineering Criteria) 2000 emphasizes “active student learning” rather than “what is taught”? The question is not “are we teaching the right material to our students?”, rather “are our students learning the right material to eventually become better engineers?”. The emphasis is on the distinction between *teaching* and *learning*. Teaching can be defined as merely instructing the students on the material. However, learning encompasses many more facets of an academic curricula. This can include integration, hands-on experiences, and internships or co-ops. Most importantly, teachers should not neglect their potential to learn from student and industry feedback and assessments. Obviously, new resources (staff, infrastructure, equipment, new technology etc) are needed to make significant, continuous improvements to Mechanical Engineering Education in Sri Lanka. However, a strong commitment from the Higher Education authorities in Sri Lanka and industry should result in tremendous long-term benefits to the nation as a whole.

J.S. Gunasekera did his Advanced Levels at Royal College and was one of the two students in the nation who got exempted from the first year of Engineering. He graduated with first class honors from the University of Ceylon (topping the ME batch in 1967). He was the First University lecturer to undertake a MSc in Production Engineering at Imperial College where he was awarded a distinction. He continued for his Ph.D. at Imperial College and returned to Sri Lanka in 1972 to fulfill his five-year obligation to the University. He migrated to Australia in 1977 to take up a Senior Lectureship in Production at Monash University. He came to WPAFB (Wright Patterson Air Force base) in 1981 on his sabbatical leave from Australia as a senior NRC fellow e and spent one year researching in metal forming and die design.

He took up a faculty position as Associate Professor at Ohio University in 1983, and was promoted to full professor with tenure in 1985. He was made the first Cruse Moss Professor in 1987 for his significant contribution to research and development in CAD/CAM and manufacturing engineering area. At Ohio University he developed at least six new courses in manufacturing processes, CAD, CAM and CIM, and attracted over $5 million in research funding. In 1990, he was responsible for forming the Center for Advanced Materials Processing, and he was made the first director. In 1991, he was appointed the Chair of Mechanical Engineering, and was re-appointed again in 1996 and in 2001. As chair he has made significant contributions to the department. He was instrumental in developing the current Ph.D. program in integrated Engineering and getting this approved through the Ohio Board of Regents. Dr. Gunasekera has advised 80 graduate students, many of whom are leaders in their respective fields

Dr. Jay Gunasekera is an internationally recognized champion of research and development in the area of metal forming and manufacturing. He has made significant fundamental contributions and pioneered discoveries in the following areas: development of a new mapping concept for the design of streamlined extrusion dies for the extrusion of metal matrix composites such as SiC whisker reinforced aluminum, development of a new upper bound solution for the extrusion of complex shapes, development of fast algorithms for quick solutions to forging and heat treatment problems, development of new techniques for the modeling of ring rolling, and the development of models for micro structure evolution during hot deformation. Dr. Jay Gunasekera has published over 130 technical publication in refereed journals and conferences. He was awarded the higher doctorate (D.Sc.) Degree by the University of London in 1991 for his contribution in research and publications in the field of manufacturing engineering. He was made a Fellow of the City & Guilds of London, which is the highest honor conferred. He is also a Fellow of the IMechE, IProdE (now IEE) and SM.