Global Status of Engineering Education

-Outcomes of the 1998 Global Congress on Engineering Education at Cracow, Poland

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Abstract

The 1998 Global Congress on Engineering Education was organized around several major themes: effective teaching methods, curriculum design and evaluation, liberal education for engineers, use of new technologies in engineering education, current issues and trends in engineering education, international collaborations, education for sustainable development, exchange mechanisms in engineering education, academic/industry collaborations, international mobility, linkages between developed and developing countries, and management of academic and engineering institutions. This paper attempts to summarize the major themes and discussions at the Congress, as well as presenting recommendations from the assembled international group of engineering educators.

Introduction

The Global Congress on Engineering Education, sponsored by the UNESCO International Centre for Engineering Education, was held from 6-11 September 1998 at Cracow, Poland. Some 140 papers from authors in 40 countries were presented, with lively discussion from the 150 Congress participants ensuing. A preprint volume published by the UNESCO International Centre for Engineering Education was distributed at the beginning of the Congress, and each paper was summarized by its author(s) to stimulate discussion, at breakout sessions during the Congress. On the final day of the Congress, plenary sessions involving all participants were conducted to allow general discussion of the conference topics, and to pull together a summary statement and recommendations. This paper attempts to capture the essence of those summary plenary sessions, and thus the essence of the Global Congress. In the judgement of the author, it provides a valuable snapshot of the status of engineering education in the World at this time.

Global Congress Discussions

Effective Teaching Methods - Several papers presented at the Global Congress stressed the need for ongoing innovation in teaching and learning methodologies in engineering education. It was noted in discussion that there needs to be variety and balance in teaching methods, and that technologies appropriate to the subject matter should be utilized. Laboratory development was stressed as a very important component of engineering education, and the integration of lectures with laboratory experiences and project work was identified as an ideal scenario**.**

It was noted that often the laboratory facilities available for engineering education become obsolete, when compared with the current state-of-the-art in industry. Congress participants, particularly those from developing countries, stressed the need for faculty members to be creative in developing innovative, inexpensive laboratory experiences for their students. Project labs, where students work in teams to solve problems, were seen as particularly useful in preparing them for later engineering practice.

From the observation of faculty members who use high technology instruction aids, it was noted that engineering students favor convenience (e.g. access to lectures on video, assignments on a Web site) higher than substance of content or quality of presentation. It was noted that many engineering faculty members still use yellow chalk on green boards, and that they needed to be motivated to move to more current presentation technologies. Some faculty apparently fear that they will be replaced by technology – an unfounded concern, according to conference participants. It is clear that faculty members must stay heavily involved in any high technology teaching method if it is to succeed and continue. It was further observed that engineering faculty members would generally profit from formal study of teaching and learning methodologies taught in the education colleges on their campuses. Competency based learning, for example, can be a successful technique for engineering schools to employ.

One basic set of skills that must be developed in engineering students is critical thinking and problem solving. These skills cannot be taught in any given course, but must be developed through a series of experiences throughout the undergraduate curriculum. The undergraduate curriculum must thus be coordinated between the faculty members involved, and cannot simply be a series of stand-alone courses.

The issue of how to deal with ill prepared students coming into engineering study from secondary schools was also discussed. It was noted that while the long term solution is to demand better preparation in prior schooling, short term solutions often require engineering faculty members to provide remediation in the early parts of the college level curriculum.

Curriculum Design and Evaluation - Project centered learning was identified in several Congress papers as a highly effective way to develop problem solving and teamwork skills in engineering students. It was noted that engineering curricula should focus on developing these types of skills, recognizing that it is not possible to cram all the knowledge that a graduate will need over his or her career into four years of courses.

Considerable discussion focussed on what kinds of mathematics are appropriate for engineering students currently. Some Congress participants argued strongly for the traditional exposure to classical math – algebra, calculus, differential equations, etc. – because such exposure develops the 'way of thinking' that engineers need. Others argued that the computer and modern manufacturing have changed the needs – and that numerical methods that allow utilizing high speed computers for modeling and problem solving, and probability and statistics methods utilized in quality control, are a more appropriate emphasis for mathematics today. Some participants suggested that currently relevant mathematics should be taught by the engineering faculty, rather than the Mathematics faculty on campus, to keep it relevant and in context. It was observed that synthesis is more important than analysis in today's engineering practice.

The preparation of engineers for international practice is a prime consideration in today's global environment. Increasingly, engineers will work across national boundaries. Graduates must understand the cultures, traditions, and languages of countries where they will work, or where their designs or products will be utilized. It was also noted that engineering education in a given country or region must reflect and respond to local conditions.

The amount of practice orientation in the curriculum was explored by Congress participants, with wide differences of opinion on the desirable amount. It became clear that engineering programs in a particular country needed to provide graduates attuned to the current and future needs of their local economies, so that there would generally be significant differences in the amount of practice orientation that was deemed appropriate by the local faculty. In some countries, 'engineering' and 'technology' schools co-exist, to meet a broad spectrum of demands for technically oriented graduates.

The Congress participants encouraged international exchanges of engineering education tools. In particular, efforts by technical societies to facilitate exchanges of software programs useful for engineering education were noted and applauded. It was observed that the growing trend to include software materials with printed textbooks was a healthy development.

Congress participants from developed countries noted a trend toward outcomes assessment as the preferred method for evaluating engineering programs, rather than the detailed technique specification of curriculum by accreditation or government bodies which has been more typical in the past. An outcomes assessment approach tends to more heavily involve industrial employers and technical societies in the evaluation process – seen as a healthy development by the Congress participants. The group also felt a strong need for systems of evaluation that would allow comparison of engineering graduates across national borders, in order to facilitate mobility of such graduates to work in the global practice of engineering. Such systems would need to examine the equivalency of results of engineering education in various countries, perhaps moving toward a global accreditation approach.

Liberal Education for Engineers - It was agreed that a liberal arts component for engineering students is appropriate and valuable, to broaden their horizons as they prepare for practice in today's complex world. One element in that liberal arts component that was seen as particularly valuable for engineering students – the history and heritage of technology. Participants at the Global Congress observed, however, that faculty members well equipped to teach such history of technology courses were hard to find.

Communication skills were also identified as a key outcome of engineering education desired by employers. Human interaction skills, key to teamwork and management of projects, were also seen as key outcomes desired from engineering education.

Congress participants also noted that a reverse flow of course offerings was also needed on campus – engineering faculty offering courses to provide technological literacy to non-engineering students.

Use of New Technologies - Computer aided instruction is well established in many of the engineering schools represented at the Congress, and examples were presented in papers in the preprint volume. Given the currently available technologies, simulation and virtual reality are particularly valuable tools for engineering education. It was noted, however, that there must be a balance between simulation and hands-on experience with real world elements.

Engineering students should also be appropriately exposed to computer aided engineering, of the type that they will utilize when out in practice after graduation. It is often difficult for engineering schools to have the latest state-of-the-art computer aided design and other computer aided engineering equipment available on campus, but sufficient exposure to the principles of computer utilization in practice must be provided.

It was stressed in discussion, however, that computer learning should not attempt to replace valuable student interactions in the classroom – with faculty and with other students. Multiple pathways to learning are needed, and can complement one another in a flexible learning environment.

Faculty members need to have motivation to develop and utilize new technologies in their instruction. They must have time released from other duties, as well as funding to provide the advanced tools needed to develop high technology educational components.

The Internet and the World Wide Web provide opportunities for engineering students to glean experiences from beyond their own campuses. Even on a given campus, Web pages provided by individual faculty members are useful in providing assignments, readings, etc. Chat pages for courses can be useful in stimulating discussion among students, and with their faculty members. Such pages can provide forums for exchanging ideas, and for team work on projects.

Distance education is typical today for much continuing education for practicing engineers, and engineering students must be prepared to utilize it effectively. Thus some course components should be provided to engineering students via video or the Internet, so that they become comfortable with such delivery methods while still in a supportive campus environment.

Current Issues and Trends - In order to keep the motivation of students high during the early years of engineering education many schools are now moving engineering courses, such as introductory design exposure, into the first or second year of their programs. Design project laboratories in the Freshman year not only give engineering students a glimpse of what their upper division courses will involve, but also provide a rationale for the detailed study of mathematics and science that are typical in the lower division years.

Concluding that it is not possible to cram all the knowledge that an engineer will need throughout his or her career into a four year curriculum, engineering faculties are providing flexibility and diverse paths for individual students – while making sure that the fundamentals such as analytical problem solving , critical thinking and design methodology are included.

Recognizing that many of today's engineering students will choose to start their own businesses at some point in their careers, some engineering education programs are stimulating entreprenaurship and commercialism in the minds of their students – and providing course or project opportunities to learn basic business skills.

As noted earlier, resource constraints in engineering schools make it difficult to have sufficient resources to continuously revamp the educational programs for engineering students to incorporate best practices at the current state-of-the-art. This has led to the development of consortia of engineering schools, where cross-institutional collaboration can lead to productive synergy in updating engineering education. One prime example of such collaboration currently is the Engineering Education Coalitions program of the National Science Foundation in the United States of America. It was suggested in discussion at the Congress that a major part of the next conference in this series should be devoted to examining the outputs of collaborative efforts such as that one.

International Collaborations - Improvement of academic programs in engineering can often be effected by collaborations at the international level – particularly in developing countries. Both collaborations between developed and developing country engineering schools, and between engineering schools in similar developing countries, can be effective. Such collaborations often rely on personal relationships between faculty members in collaborating countries, not just on formal institutional agreements.

Collaboration across national border need not be limited to institutional and faculty exchanges, but can also be valuable at the student level. Electronic communications can currently readily facilitate interaction between students across international boundaries, for information exchange and joint project work.

Congress participants felt that a standard global curriculum for engineering education was neither desirable nor possible to effect. Among other things, the curricular approach used in a particular country needs to be tuned to local needs. It was suggested that curricular ideas and trends from various countries could be shared broadly throughout the international engineering education community via the World Wide Web.

Congress participants expressed the need for mutual recognition of engineering graduates across international borders, so that they can readily practice in the increasingly global technical marketplace. To achieve such recognition, development of some form of global accreditation, tied to engineering societies, may be appropriate. Any such international accreditation would have to be quite flexible in its criteria and their application, and likely should be based on outcomes assessment rather than quantitative specifications for the curricula.

At a philosophical level, it was observed that engineers have a heavy responsibility for the health, safety and welfare of the global community – and that engineering educators must take the initiative to assure that all graduates from engineering institutions around the World measure up to the quality levels needed to fulfill that responsibility.

Education for Sustainable Development - Engineering educators and the programs they provide to their students must be geared to enhancing the environmental sensitivity of their students. Design methodologies incorporating the principles of sustainable development must be utilized throughout the education of engineers.

Standards for environmental protection, such as ISO 14000, should be highlighted during the formative period of engineers, so that their use becomes a natural part of the later practice of the engineer after graduation.

Social Impacts of Engineering - Engineering students must be taught to predict the societal impacts of their designs, and to modify those that would have undesirable impacts. It was recommended by the participants in the Congress that engineering students should have the experience of working with students from other disciplines – such as business, law, social science, architecture, etc – on joint projects, in order to get a broader perspective of how their technology interacts with society.

Engineering schools must take the responsibility of preparing students for available and appropriate jobs and career paths, so that there will be an appropriate and rewarding role for them in society when they are ready to graduate and start on their careers.

Exchange Mechanisms in Education - While in the context of a major Global Congress on Engineering Education, participants in Cracow discussed the role of such conferences in promulgating good ideas for the enhancement of engineering education. One positive aspect of such face-to-face conferences is the making of personal connections, which allows follow-up interactions and perhaps long term relationships. It was observed, however, that such conferences are overly expensive for many engineering educators who would benefit from the type of presentations and discussions that occur – such as younger faculty members, and those from poorer countries. It was also observed that there are too many international conferences on engineering education, sponsored by several organizations in an uncoordinated fashion.

It was suggested that future conferences on engineering education should have a large electronic component, allowing younger and less well off faculty members to benefit from presentations and discussions from close to their home bases. It was felt, however, that some core of participants should meet face-to-face to provide focus and interaction to such an electronic conference. It was also suggested that a series of smaller conferences – perhaps regional in scope – should be held to shape and provide input to each major international conference on engineering education.

The output publications of international engineering education are critical in providing information and stimulation to educators who cannot participate in person. The participants in this Congress recommended that the output from such conferences should be made available in both printed hard copy and via the World Wide Web. The latter should make the material available more broadly, and at more reasonable cost, to those in developing countries.

Some discussion at the Congress focussed on the articulation between advanced engineering education programs and lower level feeder schools that helped to prepare students to succeed in the engineering institutions. Feeder systems often operate within a given country, but there are good examples of feeder schools in developing countries sending successful students to advanced engineering schools in developed countries. Mechanisms to assure that the graduates of such programs return to their own regions to enrich engineering practice there need to be utilized.

Academic / Industry Collaboration - Engineering schools must interact and collaborate with the industries they serve, for mutual benefit. Only through such interactions can the engineering education provided be assured to be relevant to the current market place. Students benefit greatly from practical experience gained during summer or co-op period jobs in industry – both in terms of making the remainder of their educational programs more meaningful, and in terms of gaining practical knowledge which will be valuable in full time employment after graduation. Engineering education faculty and administrators, and the programs that they offer, benefit greatly for guidance given by industry advisory groups. Industry also often provides direct support to engineering schools, through funded research projects, equipment grants, sabbatical opportunities for faculty, etc.

Engineering schools reciprocate for this support from industry by providing a flow of well educated graduates, offering continuing education for practicing engineers, and developing a flow of research results to stimulate technical development. Schools can also structure programs to facilitate work-place learning, and establish forums for technical exchanges between engineers in industry and those in academia. Schools can also provide additional broadening dimensions for their students in order to prepare them for later management positions in industry. The bulk of education for management typically is obtained later by engineers in practice, as they begin to need it as they advance in their careers.

International Mobility - Engineering school graduates can benefit greatly from studying abroad for a portion of their educational programs. Formal exchange programs, such as the Tempus program in Europe, go far in preparing engineering students to eventually practice across international borders. Universities should prepare students for study abroad, and eventual practice internationally, by encouraging appropriate study of foreign languages and cultures – and by providing sufficient flexibility in the engineering curriculum to allow an academic term or more to be spent at a school in another country. It was observed in discussion at the Congress that exchanges of students between equally developed countries work best.

Faculty exchanges between engineering schools in different countries are also valuable, giving faculty members perspective on the broad scope of engineering education in the World and providing them with the background to instill international perspectives in their students.

Ready international mobility of graduate engineers in practice is often a problem, particularly for those who offer their services directly to the public and thus typically require formal licensure in a jurisdiction in which they want to practice. Engineering educators must work with practitioners and licensing bodies to establish equivalency mechanisms for education, experience, and other licensing requirements.

Linkages Between Developing and Developed Countries - The UNECSO International Center for Engineering Education (UICEE), which organized this Global Congress, is one major effective mechanism for developing linkages between engineering education in developing and developed countries. Conferences, publications, short courses, Web based information, etc., provide linkages at UICEE and other such organizations.

Computer and communication based technologies are increasingly facilitating interchanges between engineering educators at the international level. Satellite delivered video courses, e-mail interchanges, Web based data bases, etc., have broken down previous feelings of isolation on the part of engineering educators in developing countries.

Management of Academic Institutions - Several papers at the Congress described effective practices for the management of engineering schools and the universities within which they exist. Quality control of educational programs, through such mechanisms as accreditation and the application of total quality management systems, was seen as a high priority. The effective management of workloads for faculty, and the appropriate allocation of funding and other resources, were seen as essential to smooth and effective operation of schools.

The problem of how to deal with aging, tenured faculty members was addressed in papers presented at the Congress. Early retirement incentives, retraining through continuing education, vitalization through research involvement, etc., are possible ways of addressing the problem.

Papers and discussion at the Congress also addressed the issue of how to best utilize feedback on the educational experience from students, graduates, and employers. Formal outcomes assessment methodologies can be one effective way to utilize such feedback for the continuous improvement of engineering education programs.

Conclusions and Recommendations

With respect to undergraduate engineering education, it was agreed that continual refreshment in focus, content, and the latest teaching tools was required. It was noted, however, that the limited time spent by students in their undergraduate engineering educations did not allow for learning all that was needed for a 40+ year career, and that a base had to be built for lifelong learning.

Evaluation of the effectiveness and value added in engineering education was heavily discussed. It was agreed that peer evaluation through voluntary accreditation is valuable. Outcomes assessment appears to be growing as a desirable measure, replacing detailed curriculum specifications.

In graduate education, practice oriented masters degree programs for engineers were seen as growing in popularity as the “first professional degree”. Traditional MS and Ph.D. paths were still seen as valuable for those planning to enter R&D, teaching, or advanced technical practice.

Offering of continuing education programs was seen as a responsibility and opportunity for engineering schools, along with offerings from industry, societies, and commercial sources. It was observed that engineering schools need to involve faculty members who understand current industry requirements, and who can teach at the current state of the art. The use of advanced technologies to deliver such continuing education offerings into the workplace or home was seen as cost effective and key to broad utilization.

Industry advisory groups for engineering programs were seen as key to effective industry collaboration. Engineering schools also need instructors from industry, other support from industry for their programs, and the opportunity to have students directly exposed to industrial experiences.

It was observed that employers want engineering graduates with technical expertise, but also with considerable broadening. Humanities and social science exposure, communications skills, business and entrepreneurial stimuli, international experience, and teamwork preparation were all seen as desirable attributes.

It was strongly agreed by the diverse participants at the Congress that engineering students need to be well prepared for international practice. The exposure of engineering faculty members to international experiences is critical in allowing them to be appropriate role models and resources for students. It was argued that engineering schools in developed countries can and should assist those in developing countries, for mutual benefit.

Recommendations from the Congress included:

- A near future international conference on engineering education should contain a comprehensive coverage of the results of major educational programs currently revitalizing this field in several countries, such as the Coalitions Program of the National Science Foundation in the USA.
- Faculty in engineering schools need motivation and incentives to make greater utilization of new high technology teaching/learning methodologies.
- An international quality control system for engineering education is needed, perhaps based on the accreditation programs which utilize flexible criteria and outcomes assessment that are currently evolving in several countries.
- A continuing education system for faculty that can assist developing countries in keeping their engineering education programs current should be developed and updated regularly, perhaps by the UNESCO International Centre for Engineering Education.
- A near future Congress of the type held here in 1998 should be conducted electronically (satellite video, Internet discussion, etc) to allow broader involvement of engineering faculty participants, particularly younger faculty and those in developing countries. The year 2000 was suggested as a target date.

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