Global J. of Engng. Educ., Vol. 3, No.1
Printed in Australia

Quality Engineering Education: Student Skills and Experiences

Saad El-Raghy
Faculty of Engineering, Cairo University, Cairo, Egypt

Several surveys from industrialised and developing countries have revealed industry's need for quality engineering education to contain a component of skills and experiences. This paper focuses on three of the more important of these skills, namely, hands-on experience gained through experimentation, life-long learning and communication by speech, writing and graphics. Each of these skills is based on knowledge and extensive training in and out of the classroom. Three practices followed to acquire the skills and experiences are presented. Industrial training introduces the student to real life; it may be in summer vacations or as an integrated part of the engineering programme. The capstone or graduation project develops the acquired skills and introduces the student to new ones. International co-operation as student exchange for study or for training diffuses cultural diversities and builds attitudes of tolerance that are highly needed for better international engineering co-operation.

INTRODUCTION

Quality engineering education is composed of elements relating to students, faculty, pedagogy and facilities, elements that are presented in separate papers in this issue of the journal. Besides the solid theoretical knowledge included in the basic sciences, engineering sciences and professional courses, a good engineer is expected to acquire additional technical and non-technical skills. Some of these skills may be gained in the classroom using computers, or in laboratory experiments. Other skills, such as communication and cultural awareness, may or may not be generally included in a student's courses. However, the engineering student should be exposed to these before graduation.

This paper covers some of the basic skills and experiences needed for an engineer, and how and where to gain these experiences. Some examples from developed and developing countries are given. The author's experience in education and his association with industry are reflected in the present work. Also, different studies carried out in other parts of the world are taken into consideration [1-3].

SKILLS AND EXPERIENCES

The engineering profession covers a wide spectrum of activities, including design, fabrication, operation, maintenance, marketing and research and development. All these activities need a solid theoretical background to a different extent, and, at the same time, require skills and experiences of a different nature. This section discusses three of these skills, namely: experimentation and measurements, life-long learning and communication. There are certainly other skills that should be acquired by engineers, such as managerial and negotiation skills, but many of these must be gained after graduation. Also, experiences gained during graduate studies are not discussed here; this paper deals only with what should occur during undergraduate education.

Experimentation and measurements (*hands-on-skills*)

Measuring physical quantities with easy hands-on is of vital importance to the majority of engineers. This skill is acquired during all stages of education; quality engineering education programmes cannot over-emphasise these experiences. Laboratory classes are essential for both the basic and engineering sciences. Colleges of engineering must invest in modern laboratories and equipment. Good space and a sufficient number of kits must be available so that each student can share in carrying out experimental measurements. Student are to be encouraged to write their own observations and to relate them to their theoretical background and related life cases wherever applicable.

Computer simulated experiments help students understand the subject in their own time and to comprehend parametric studies. These virtual experiments add to students' experiences and appreciation of the physical laws as well as improving computational skills. However, it is improper to consider computer simulated experiences as a replacement for laboratories with real hands-on experiments.

Many basic skills and workshop experiences are learned by students in industrialised countries at the secondary school level, both at school and at home. On the other hand, their counterparts from a developing country, in general, may lack these experiences. It may be true that young people in developing countries have never touched, or perhaps even seen, a micrometer or an voltmeter before their university studies begin. Therefore, some engineering education institutions in developing countries that care about quality include workshop courses as a mandatory requirement for the first (preparatory) year students. The student should spend something in the order of two hours per week for a full term in the workshop going through basic engineering experiences, such as measuring physical quantities, doing simple metal cutting and joining, etc. Such programmes may sound primitive, but they are highly recommended. Since it is clear that computational aspects in engineering will become even more pervasive on a global basis, high quality engineering programmes must provide basic computer skills, and all engineering students using a computer laboratory should master these.

LIFE-LONG LEARNING

The working life of a practising engineer should be about 40 years following graduation. During this period, in all engineering disciplines the profession will go through major changes, both in knowledge and in tools. Although it is true that basic engineering sciences, such as thermodynamics and fluid mechanics, do not change very much, new computational techniques and applications will be developed. Modelling and physical simulation are now day-to-day tools without which process control would be almost impossible. The need for interdisciplinary work is more and more the general rule rather than the exception. A modern production plant and a modern construction site use the same language and follow the same management techniques, often times even using similar software. It is no longer mechanical engineering versus civil engineering. A quality engineering education programme should prepare the engineer for this ever-changing situation; self-learning skills help the engineer face new challenges, circumstances and new opportunities.

Assignments and technical report preparation over a specific part of a course are good ways of building self-learning skills. Many of these skills may also be developed during the *capstone project* usually included in the final year of the undergraduate programme or during any associated industrial training, such as co-operative opportunities that may be a part of or associated with the engineering programme. Self-learning needs other skills, such as rapid scanning and reading, index searching through modern databases, subject definition and identifying key words. Self-learning also comes through experimentation, learning by doing, and interacting with experts.

Life-long learning is both a need and an attitude. This need may be fulfilled by either attending continuing education courses or by self-learning through reading and studying. It is not recommended here to rely only on one form of life-long learning. Some subjects need professional, continuing education, where it is more economical and better time managed. However, self-learning remains the major path to life-long learning and the necessary skills should be developed to accomplish life-long learning while the student is an undergraduate.

COMMUNICATION

An engineer works generally for an organisation in a team. In a study by the American Society of Engineering Education, communication was identified as the major required skill for all practising engineers [3]. Communication may be oral or written. As with any skill, communication needs basic knowledge and accumulated experience. Correct language and logic are essential.

Language is the carrier of ideas during conversation or in writing. An inefficient carrier, namely incorrect language or ambiguous comprehension, may distort a good idea. A quality engineer working in their home country should master their mother tongue, both vocabulary and grammar. On the other hand, the growing nature of international engineering activities makes it essential for a practising engineer to know at least one foreign language. In major projects all over the world, and even in some small projects in some countries, multinational groups of engineers work together. Thus, during the construction of the Cairo subway, French engineers communicated with their Egyptian colleagues in English.

Technical writing is a popular subject with good textbooks. These books do not cover language only, but go through the basic components in the preparation of a good report, paper or thesis. Some quality engineering schools include a course on technical report writing in their programmes as one of the core courses. A technical writing course is recommended to be available for all engineering students, or at least as a highly recommended elective.

Graphical representation is a basic engineering communication skill. It is true now that there are graphics software packages ready for use. However, this does not exclude the need for engineering students to learn the basics of engineering drawing, including cross-sections, projections and assembly. Hand-prepared sketches remain an effective tool for engineers to express their technical ideas to colleagues and others they work with.

EXAMPLES OF PRACTICES

In this part of the paper, three practices adopted by engineering programmes in order to provide students with basic skills and experiences are discussed. Industrial training exposes students to real life work. The project has a dual function, utilising acquired experiences and knowledge besides requiring accumulated experiential learning. International co-operation through student exchanges for study and for training diffuses cultural misunderstandings and promotes tolerance needed for international engineering practice.

Industrial training

Working in an industrial firm for a period during the course of study allows a student to see the real meaning of engineering in a workplace environment. This adds to the appreciation of physical quantities that were measured in the laboratory at the university. Appreciation of physical quantities is a vital experience for a quality engineer no matter what form employment takes. Summer training may be considered as a pilot engineering practice during which the student will further develop experiences and gain new ones. Students may start asking questions that would trigger their attitude to gain even more knowledge and skills.

Some engineering schools expect their students to spend sometime with local industry in the summer vacation. On the other hand, summer training is mandatory in a few engineering programmes. By the end of summer training, the student would have added both technical and non-technical experiences to engineering knowledge and professional skills. The student should be required to submit some form of report describing the training place and the activities that were performed, and to present views about the conditions of the work experience. The level of documentation of observations should be evident in the report submitted to the university. The quality of this document may be considered in the student's overall grading.

Proper management of summer training is needed. Student placement can be a time and effort consuming process. Suitable timing of exposure to the appropriate industry should be decided carefully. This is not an easy task in some countries due to the small size of the local industry compared to the number of engineering students. A good relationship between the university and industry facilitates the placement of students for training. Some type of industry supervision should be offered by the training place, while university staff may pay visits to follow the progress of students during their time in the industry.

In some engineering education systems, industrial training, under various titles, is integrated into the programme, eg sandwich programme (UK), co-operative system (Germany) or enhanced engineering experiences for engineers (USA) [4]. These systems, although they may have different names and even style or organisation, surely are skills-oriented programmes. The knowledge component should not be neglected and the experience acquired before graduation is important. This should be considered in accreditation systems [5]. This comes through more systematic exposure to industry; with the sequence of engineering courses followed in such a way that the student could go to the training place as early as the end of the first year.

The project

The project may be considered as the ultimate exercise presented to the student before graduation to measure accumulated engineering knowledge and experiences. At the same time the project itself should provide the student with some new skills and information, and strengthen acquired ones.

Looking through different engineering education programmes all over the world, one can see the diversity in the *project* management, with different assignments, allocated time, end products and evaluation [6]. Project assignment varies from a small and specialised research project to the analysis of an integrated industrial project; the design of specialised equipment or a structure is another typical engineering project.

The amount of work expected depends on the time allotted. The activities performed during a capstone project may cover one or more of the following:

- Data collection
- Critical literature review

- Laboratory experiences and tests
- Mathematical modelling
- Software application
- Industrial visits (which may be as long as a few months)
- Design and/or assembly
- Process analysis
- National project analysis
- Documentation and technical writing

Students should be encouraged to choose open-ended topics for a project. An open-ended project is more challenging and requires students to utilise all the knowledge and experiences they have accumulated over their years of study. Each student may be assigned an independent project; however, it adds to an engineer's experiences if the capstone project is co-operative in nature. The trend now is to get a group of students of the same department or even of different departments looking at a multifaceted subject. Teamwork is an important characteristic of an engineer, and the project should help to develop this.

It is not fair for the project to be treated as a single course, although this is the case in a few places. The allocated time may require at least the equivalent of six credit hours, (two semester long courses); the expected working hours may be twice as many. There is nothing wrong with sparing some weeks up to a few months for the student to get the project done. Of course, the project takes on a special weight in grading the student, and is often considered to be an indication of the quality of knowledge and experiences that the student has accumulated during the undergraduate engineering education programme.

International co-operation

Globalisation of the business community is pushing the need for a multicultural engineering workforce. In the oil industry, as in bigger construction projects, multinational engineers are co-operating. For good industrial relations to pertain, a high level of communication skills are needed and cultural diversities have to be understood and accepted. This calls for the proper formation of the engineers who work in these conditions. Major companies prepare their staffs for these diversities. At the university level however, students can acquire good experience both in the classroom and during industrial training.

Some agreements between universities of different countries contain articles relating to the exchange of students for one semester or longer, perhaps even up to one year. During this period, the foreign students attend lectures and perform laboratory work exactly as the students of the host country. They share in other student activities as well, such as seminars, sports and industrial site visits. Upon returning to their home country, this experience will be memorable as a different cultural, social and learning experience. During these times, differences in language, in religion and in the engineering way of thinking learn to be tolerated. Tolerance is the cornerstone of *education for peace*, promoted by UNESCO. Exposure to other societies in such a friendly atmosphere as the classroom is a very good way to create tolerance. In business this cultural understanding is an asset to the management of international projects.

Training in industry abroad for students of science and technology is now widespread and attractive to all parties in different countries. Students look for these opportunities; major industrial firms are interested in promoting them, and engineering colleges need to encourage them. The benefits of abroad training are highly recognised now. Unfortunately, a large share of this training abroad is based on the self-initiative of the student, or through bi-national agreements and professional societies. Universities need to become more pro-active in promoting international exchanges. Another example is the International Association for the Exchange of Students for Technical Experience (IAESTE), which administers part of this activity. It was founded in January 1948. This association is a confederation of 61 national committees representing the academies, industry and students in each of these countries.

The annual reports of the IAESTE provide concise and informative statistics on the numbers of students trained abroad through this association from different countries, north and south, and for different disciplines [7]. These numbers grew from 108 students trained abroad in 1950, to 1050 in 1995, in addition to another 200 students who were offered places but who could not participate due to personal difficulties or administrative reasons.

The annual meeting of the IAESTE is an active gathering to arrange the exchange of students for training, as well as a platform to exchange ideas and experiences in engineering education between representatives of these countries. The industrial training abroad arranged through the IAESTE is small in size, yet it is to be considered as one of the fruitful examples of international co-operation for quality engineering education programmes.

CONCLUSION

This article is written to discuss some primary skills and experiences - experimentation, communication and life-long learning - offered by quality engineering education programmes. It is not intended to be inclusive of all skills; mathematical and computation skills are not discussed. Also, other skills to be acquired after graduation were not included. The focus is on skills and experiences needed by the majority of engineers. Three examples of practices followed by different engineering programmes are presented. Two practices selected for discussion were industrial training and the capstone project; most colleges of engineering follow both of these practices. The third practice discussed here is international co-operation in education and training, which helps to diffuse cultural diversities and to encourage the tolerant attitudes promoted by UNESCO.

Within each of the skills and actions, sub-issues were included. Thus, communication skill needs the individual to master the mother tongue, the carrier of ideas in speech and in report writing, as well as a foreign language. The capstone project was given as one action for developing skills before graduation, although it may by considered as a measure of a student's acquired knowledge and experiences, or outcomes assessment.

Based on industry needs sensed in different parts of the world, we cannot over-emphasise the need for quality engineering education programmes to provide ways of developing the requisite skills of students before graduation.

REFERENCES

1. Nguyen, D.Q., The Essential Skills and Attitudes of an Engineer. *Global J. of Engng. Educ.*, 2, **1**, 65-74 (1998).
2. El-Raghy, S.M. and Khalaf, F., Industry Needs of Engineering Education, Case Study. *Proc. Inter. Conf. Engng. Deans and Industry Leaders*, UNESCO, Paris (1996).
3. Middendorf, W.H., Academic Programs and Industrial Need. *J. Am. Soc. Engng. Educ.*, 835-837 (1980).
4. ABET Accreditation Criteria 2000. ABET Washington (1997).
5. Enhanced Educational Experiences for Engineers. (E4), Drexel University (1996).
6. Several Colleges of Engineering Year books.
7. IAESTE Annual Reports, IAESTE Secretariat, London (1995).

BIOGRAPHY

Dr Saad El-Raghy is Professor of Metallurgical Engineering at Cairo University. He holds a BSc degree in Metallurgical Engineering from Cairo University, MSc and a PhD from the University of London, England. He worked from 1962-1964 at the Delta Steel Mills. He joined Cairo University as a lecturer in 1970 and was promoted to Associate Professor in 1975 and to Professor in 1980. From 1984-1990 he was the Vice-Dean for Postgraduate Studies and Research of the Faculty of Engineering. At that time, the existing *regulations of postgraduate studies* were laid down.

Dr El-Raghy spent three long visits abroad: University of Nancy, France 1976-1977, University of Aachen, Germany 1979, and University of Utah, USA 1980-1981. He has published more than 75 scientific papers, supervised 32 MSc degree students and 15 PhD degree students in the fields of metal extraction, corrosion and corrosion control.

Dr El-Raghy is a member of TMS, NACE, and a fellow of the Egyptian Society of Engineers. He is a member of the board of the Holding Company of Metal Industries, and is Chairman of the Committee of Technological Development at the National Academy of Science and Technology.

He has published 12 papers in engineering education, and was the Secretary-General of the *WFEO-UNESCO Third World Congress on Engineering Education* (1994). Dr El-Raghy is a member of UNESCO's International Committee on Engineering Education, and of the UNESCO International Centre for Engineering Education (UICEE).

Global Congress on Engineering Education: Congress Proceedings

edited by Zenon J. Pudlowski

These Congress Proceedings contain papers submitted for the first *Global Congress on Engineering Education,* held at the University of Mining and Metallurgy (Academia Górniczo-Hutnicza), Cracow, Poland, between 6 and 11 September 1998. The Congress incorporated three on-going, major and extremely successful international meetings: the *5th World Conference on Engineering Education*, the *4th East-West Congress on Engineering Education* and the *1998 International Congress of Engineering Deans and Industry Leaders*.

Close to 140 papers included in the Congress Proceedings present and discuss research and developmental activities in engineering education carried out throughout the world. Particular emphasis has been placed on globalisation of engineering education to stress the importance and relevance of collaboration between universities worldwide. Of particular interest and value are the many papers from authors in developing countries and countries in political, economic and social transition. Some of these papers present considerable achievements made over the last few years, while others demonstrate that some of these countries still grapple with fundamental changes to be made to their systems of engineering education.