Engineering Education: Future Trends and Advances

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Abstract: Engineering developments and innovations are being brought forward at an increasingly rapid rate, thereby forcing engineering educators to adapt to new realities. A reasoned response to such pressures is essential, because engineering education, and more broadly the engineering profession, advances best if challenges are identified early and well managed, opportunities are sought and where possible exploited beneficially, and speculation is made on future trends, based on logical assessments and reasoned arguments. In this article, the views of the presenter are described, based on his experiences as an engineering educator, administrator and practitioner, on future trends in engineering education, and on many related challenges and opportunities. This topic is of great importance because the advancement of engineering education is strongly influenced by its challenges and opportunities, as well as by future trends. The objective of the presentation is to improve engineering education by increasing awareness of these topics among engineering educators and others, and promoting active consideration and debate of potential actions in response to these issues.

Keywords: Engineering, education, challenges, opportunities, trends, future

1 Introduction

Despite its numerous achievements and successes, many challenges and opportunities face the engineering profession. Similarly, engineering education faces many challenges and opportunities. The development of engineering requires that these challenges be properly addressed and opportunities be fully assessed and exploited beneficially where possible, and that future trends be tracked and speculated upon in a reasoned manner. Given the multitude of ways that engineering education supports the profession, it is important that challenges and opportunities facing engineering education, and possible future trends, be understood and acted upon.

In this article, the author presents his views on some of the challenges and opportunities facing engineering education and, from them, suggests possible future trends and developments. Although challenges, opportunities and trends in engineering education can be general or specific to individual engineering programs or faculties, this article concentrates on general factors.

The objective of this article is to contribute to the development of engineering education by suggesting possible future trends, and fostering continued discussion of and appropriate action on the challenges and opportunities facing engineering education. The article extends previous work by the author on future trends in engineering education [1]. If challenges are to be properly addressed, opportunities optimally exploited, and future trends clearly anticipated, it is important that these topics be continually debated. Since not all challenges to engineering education can be easily predicted, professionals involved in engineering education need consider the possibilities regularly in order to be prepared for unexpected challenges.

2 Background

The engineering profession is a significant contributor to a country’s economic development, standard of living and societal well being. Engineering also affects the cultural development of a society and the environment.

Given the significance of engineering, engineering education is important and leads to benefits to members of the public and more generally society.

Challenges [2-6] and opportunities [4-7] relating to engineering education and future paths and visions [5,8-10] have been examined for many countries in the past, and a variety of views have been presented. The challenges are widespread, and often specific to the country or institution, and often involve resources. The opportunities are similarly varied, sometimes being of a general nature but...
more often specific to the institution. Many opportunities refer to advanced and novel pedagogical approaches to teaching and facilitating learning.

Some have described changes [11-14] and reforms [15-17] occurring in engineering education as well as its evolution [18]. Others have suggested entirely rethinking engineering education [19] or transforming it [20]. Recommendations from different stakeholders, including students, faculty, industry and society, have been put forward [21], and future trends have been investigated and predicted [22-25].

Although this article is intended to be general, much of it is informed the situation in Canada, for which several studies have been carried out [4,18,23,24,26], although most of the topics discussed are applicable in other parts of the world. Of course, the situation in some countries is quite different than in Canada, e.g., the developments in engineering education have been examined in developing countries like China [27]. Other studies have addressed educational trends in specific engineering disciplines, such as electrical and computer [28], chemical [29], environmental [30], biological [31], manufacturing [32] and nanotechnology [33]. Although these articles are focused on disciplines, many of the trends identified are general in nature. Others have addressed future trends in international education [25], lifelong learning [26], and uses of advanced information and communications technologies and related learning objects in engineering education [34-36].

3 Challenges, Threats, Opportunities

3.1 Challenges and Threats

Many of the challenges that face engineering education can be categorized into two groups. The first relates to curriculum, teaching and learning, while the second involves issues that are treated here as the engineering education environment.

3.1.1 Curriculum, teaching and learning

The main challenges and threats considered here in the areas of curriculum, teaching and learning relate to quality, pedagogy and relevance. Details on these are provided below.

Achieving and maintaining high-quality engineering education involves ensuring simultaneously that excellence exists across all existing activities in a given engineering program and striving for excellence in new areas. Here, I refer to quality in its most general and broad sense. Since it is desirable to avoid reducing the quality of existing activities when embarking on new initiatives, an appropriate balance needs to be struck between broad and general excellence and targeted areas of excellence. Many of other challenges and threats discussed in this section also relate to quality.

Pedagogical challenges regarding teaching and facilitating learning exist, from the perspectives of both the teacher and the student. Often student learning is not as good as expected, rendering it difficult to ensure all students master the material presented. Sometimes students need varied approaches tailored to their types of learning [37-40]. Furthermore, engineering programs need to improve student problem-solving and learning skills, and instill an ability to continue learning throughout a career [26]. Such a work ethic allows graduates to adapt to challenges encountered on the job.

The relevance of engineering programs is sometimes questioned as they are continually challenged to update and improve. New engineering disciplines, which will almost certainly continually arise, must be accommodated within engineering education. In addition, engineering curricula must include appropriate amounts and types of technical material such as mathematics, sciences, and engineering sciences and design, and continually improve to maintain relevance, effectiveness and, where applicable, accreditation. Also, the program environment must be well maintained, including appropriate support personnel and well equipped laboratories and computer facilities. Many discuss methods for engineering curriculum development [41].

Two further challenges and threats relating to engineering education are worth noting. First, the need to enhance and expand design in engineering education is often cited [42,43]. Some programs approach this matter by collaborating with industry so that student design topics are real and the industrial partner contributes expertise, while others approach this issue by ensuring engineering design is covered in each year of a program, with increasing sophistication and comprehensiveness in successive years and culminating in a capstone experience. Second, industry’s continual call for a wide range of non-technical skills to complement technical knowledge must be addressed, although this cannot be at the expense of sacrificing technical content. For example, engineering students are now expected to have leadership qualities, an ability to work in teams or independently, strong communication skills, and an understanding of
economics, business, management and entrepreneurship. Furthermore, they are called on increasingly to have a good knowledge or appreciation of of environmental stewardship and sustainable development [44,45], the socio-political and cultural implications of engineering [44,46], risk and safety assessment [47], and the legal and ethical ramifications of engineering practice [46].

3.1.2 Curriculum, teaching and learning
Various challenges and threats relate to the engineering education environment, which is taken here to be issues other than curriculum, teaching and learning. These include attaining sufficient resources, establishing meaningful linkages and strong reputation, attracting students and addressing external competition.

A daunting challenge is embodied in attaining the resources needed for engineering education, including human (faculty), financial and equipment. A growing shortage of faculty members over the next several years is predicted by many, partly due to competition from industry and international universities. This will make it difficult to recruit and retain faculty and to keep morale high, and simultaneously require support to allow faculty to achieve their aspirations in teaching and research. Achieving sufficient financial resources on a sustained basis is a critical challenge, regardless of how much funding comes from tuition fees, government grants and industry. Deregulation of tuition fees in recent years has changed the economic environment for many engineering faculties, making it even more difficult to achieve a financial balance.

To attract qualified students and provide a fulfilling education, engineering educators need to address student concerns, including helping students attain their highest possible academic potential [48], improving the student experience, treating students respectfully and fairly, and improving employment prospects in meaningful engineering careers and co-op and internship placements. The latter is becoming increasingly difficult in fields and locations where significant offshoring of engineering work is occurring. Nevertheless, to improve the relevance of engineering programs and meet industry needs, it is important to develop and maintain strong linkages with industry and other professional bodies. Ways to enhance university-industry cooperation are continually sought [49]. Additionally, to justify support from government, industry and alumni, engineering educators must continually enhance their reputations and public image.

New forms of competition must be taken into account in planning. Alternative modes of engineering education such as distance education are growing, and the role of distance education will become particularly significant in supporting lifelong learning and continuing professional development [26]. In addition, private schools are now being introduced in some areas where only public schools had previously existed.

3.2 Opportunities
Governments, the media and the public understand to some extent the importance of advanced technology to the economy, standard of living and societal welfare. Many governments have identified the needs for greater advanced technology and launched related initiatives. Appreciation of the significance and importance of engineering education allows the case to be put forth for support. Some of the opportunities for engineering education are discussed, which can permit it to build on public and government support, are as follows:

- **Enhance existing strengths.** A degree of excellence has been attained at most engineering universities, providing the opportunity to build on strengths. Collaborations between universities with similar strengths, or among university and industry partners with common interests, can be exploited to permit an area in an engineering program to be enhanced markedly. Also, existing areas of strength often facilitate linkages with other disciplines, e.g. the merging of a faculty with strengths in biological and chemical engineering with the growing area of biotechnology could lead to innovative interdisciplinary programs in biotechnology and/or environmental engineering, and the linkages between nanotechnology and medicine could be exploited to yield new advances in health care. In addition, linkages between engineering and non-technical disciplines can lead to beneficial programs (e.g., engineering management).

- **Build new areas.** New areas of engineering focus are justifiable in some instances, often by leveraging existing strengths. Opportunities to move into a new focus area can emerge relatively quickly when the area is anticipated to lead to significant impact on the economy or society (e.g., mechatronics and nanotechnology, computational engineering, which focuses on the use of computational methods in various engineering disciplines, and health engineering).
• **Adopt new methods.** New pedagogies and methods for teaching and facilitating learning are available, that can improve the process and outcomes of engineering education. Advances in information and communications technologies make it possible to use these tools in innovative ways in delivering education and facilitating and enhancing teaching and learning [34,35]. Ways to exploit the opportunity these advances present are numerous and likely to grow significantly in the future. It will likely play an increasingly important role in facilitating distance education, thereby supporting lifelong learning.

### 4 Future Trends

Engineering education has evolved since its origins. One of the strongest features of engineering education, in fact, has been its resilience and flexibility, and its ability to adapt and evolve as new challenges, opportunities and new realities become apparent. Some have attempted to provide pathways to the future of engineering [50]. Despite the appearance of confusion that sometimes seems to be associated with engineering education, there are discernable trends. Many of these trends are discussed here, where they are grouped into several categories: advancing fields, refocusing priorities, enhancing professionalism, advancing teaching and learning methods and increasing diversity.

#### 4.1 Advancing Fields

Emerging engineering fields in new areas are likely to increasingly develop in the future corresponding to advances in science. It is not easy to predict these areas with certainty, but based on past trends some examples of new engineering fields that have begun to develop, or may develop or expand, include nanoengineering, biomaterials and biotechnology engineering [31], computational engineering, health and genome engineering, and engineering for sustainable development [51] and sustainable energy [52].

#### 4.2 Refocusing Priorities

The main future trends around engineering education priorities, which I anticipate may be modified or expanded, relate to creativity, innovation, design, engineering methods and fundamentals, multidisciplinary studies and independent learning.

I expect that there will be a greater focus on ensuring engineers are more creative and innovative, as traditional engineering activities become more frequently offshored. These attributes can help keep them at the forefront of the engineering profession. Integrating innovation and continuous improvement into engineering education is often cited as essential [53].

I also expect the focus on increasing the design content and quality of engineering curricula to continue. This trend will likely be tied to an increased focus on innovativeness and creativity in engineering education, given those factors are crucial to engineering design, and yield more competent and productive engineers. Some have advanced design engineering through various methods, such as engineering clinics [54]. An increased focus on engineering design will likely increase the distinction between engineers and applied scientists. Applied science will likely remain more focused on science applications in a narrow and specialized sense (e.g., forensic science and radiation science). A difference between applied science and engineering programs in Canada is that only the latter are subject to accreditation assessments and the regulations of the professional licensing bodies.

I anticipate that engineering education will incorporate a stronger focus on instilling in graduates a better appreciation of interdisciplinary and multidisciplinary engineering, especially as the barriers between traditional engineering disciplines become more blurred or dissolve and new disciplines emerge. In addition, I anticipate the development of more interdisciplinary and multidisciplinary programs. At some universities, programs exist like automotive engineering, sustainable energy engineering, “general” engineering and nuclear engineering, which incorporate elements from a range of engineering and non-engineering fields.

Another trend based on refocusing that I expect is an increased focus on engineering methods and fundamentals, with a corresponding reduction on discipline-specific details. Although new technologies in the future will motivate faculty members to try increase discipline-specific content in engineering programs, such a response is unsustainable, as it usually leads to overly compressed curricula. Thus, I expect that engineering curriculum developers to accept that not all discipline-specific content can ever be covered in an engineering program, and to focus more on fundamentals and engineering methods and approaches, which tend to provide students with the tools they need to address discipline-specific tasks. Much discipline-specific knowledge will be attained in the workplace, by networking through face-to-
face and virtual communities of practices and via lifelong learning, although rudimentary discipline-specific knowledge will remain a core component in an engineering program. This approach will, I feel, improve the core ability of an engineer to solve problems and address opportunities, regardless of the specific topic at hand. In some cases, entire programs may focus more on fundamentals, such as the relatively new programs in Integrated Engineering at the University of Western Ontario in Ontario and the University of British Columbia. A renewed focus on fundamentals and methods may also occur in other fields such as medicine, where many of the same concerns are prevalent.

In a trend somewhat related to the previous point, I expect a renewed focus on independent learning. Engineers in the future will have to increasingly be able to learn on the job, as not everything can be covered in a program. To support this ability, I expect engineering students to be assigned more independent study in order to better prepare them for their careers. Greater use of information and communication technologies will facilitate this shift in learning.

4.3 Enhancing Professionalism

Several future trends around professionalism are likely in the future, the principal ones of which involve the environment, ethics, professional attributes, business, management, entrepreneurship and globalization.

As environmental issues and concerns continue to grow, I anticipate that, engineering education will place a greater emphasis on ensuring engineers have a broad awareness of the implications of their actions on the environment, and a better understanding of their role in environmental stewardship and responsible environmental behaviour. I expect terms like “design for environment,” “life cycle analysis” and “industrial ecology” to become more common in the engineering lexicon.

I anticipate a greater focus in engineering curricula on ensuring engineers behave ethically and respect their duty to protect the public, especially in light of the seriousness of the potential dangers of unethical practices in engineering, and the strong public disapproval when inappropriate ethical behaviour is revealed in public or private sector organizations. Some have stated that new engineers will have a better balance between employability and social responsibility than may have been the case in the past [55]. Concern about professional ethics, although essential in engineering [56], is of growing concern in many professional programs.

I anticipate a continued emphasis in engineering programs on ensuring graduate engineers exhibit professional attributes and behave professionally. The respect of the engineering profession and the trust of the public demand such professionalism. One way a stronger sense of professionalism may be instilled is increased use of co-op work terms and internships. The proven practice of ensuring engineers behave professionally by example, through exposing them to workplaces where professional behaviour is demonstrated, will likely become more pervasive. Another professional attribute that will likely receive increased attention is communications skills. Engineers’ abilities to communicate effectively not just with each other but with others in companies and the public necessitate strong communications skills, and employers increasingly expect such skills.

I expect engineering programs to expand coverage of business, management and entrepreneurship. These attributes provide graduates with improved business and management skills, so that they can work more productively in organizations and companies, be more effective if they take on managerial or leadership roles, and become entrepreneurs if they develop engineering innovations with good potential for commercial success. At some universities, engineering and management programs integrate skills in business, management and entrepreneurship. As a distinct skill within these areas, I expect engineering students to be provided with an increased awareness of globalization. Since engineering, as a science and art, is for the most part independent of country, I do not expect the technical bases of engineering programs to be significantly altered due to the effects of greater globalization. Rather, following much work on engineering in the global context [57], I expect engineering programs to invoke in graduates a greater awareness of globalization trends, especially in business, legalistic and cultural respects, so they can be productive in international settings.

4.4 Advancing Teaching and Learning Methods

The main future trends around teaching and learning methods in engineering education are likely to new teaching and learning methods, information and communications technologies and virtual and simulated laboratories.

I anticipate that there will be expanded use of new methods to facilitate teaching and learning, taking advantage of the many new methods being
proposed or tried to improve educational activities and student learning. For instance, active learning and reflection have been in various areas of engineering education [58].

I further expect that engineering education will evolve to make greater use of information and communications technologies, as tools that can help improve teaching and learning. Such developments will increase accessibility of students to engineering programs and allow them greater flexibility in terms of how, when and where they study. Some universities are adopting such tools heavily and integrating them into the learning approach used. This approach often provides distinct advantages over traditional education methods.

To enhance engineering skills and to take advantage of modern computing power, I anticipate increased use of virtual experimentation and computer simulation in laboratories. An additional benefit of this trend is its ability to offset the increasingly prohibitive costs of laboratory equipment, although the trend is mainly motivated by recognition of the reality that virtual design and computer simulation will play increasingly important roles in engineering in the future. I expect that more laboratory experiences in engineering curricula will utilize virtual experiments, computer simulation and online experiments. Attempts to improve teaching experimentation using these techniques have been reported [36,59-61], including the use of remote labs [62].

4.5 Increasing Diversity

I expect that diversity in the engineering profession will increase. For instance, I expect that, over time the efforts being expended to attract women and other minorities to the engineering profession will pay off, and the proportions of women and minority groups in engineering fields where they are underrepresented will increase. I further expect that this increased diversity will be increasingly reflected in engineering programs, both in the student body and faculty, in line with the objectives of many proponents of diversity [63].

5 Further Discussion

The treatment in this paper may appear overly simplistic, since the points raised are discussed independently. This is mainly done for organizational purposes, and it is noted that many of the challenges discussed above are interrelated, as are many of the opportunities. Additionally, the trends discussed are also not necessarily independent, and exhibit some overlap and relations.

It is not possible to state with certainty what the future holds in store for engineering education. But, one can examine past trends and patterns, as well as predictions about the future, and speculate on what changes are likely to pervade engineering education. In this section, I make several speculations, acknowledging that, although I have communicated with many people and examined many resource materials on the topic, the views expressed are very much skewed by my limited personal experience, which includes many years as an engineering professor, and service in a variety of university leadership roles (founding dean of a faculty of engineering and applied science, department chair, school director) and as president of an engineering society and institute.

6 Conclusions

Many challenges and opportunities face engineering education. These along with other factors may lead to changes in engineering education in the future. The views expressed by the author in this article on some of the challenges and opportunities facing engineering education, and possible future trends, are intended to promote discussion of and appropriate action on these issues. It is hoped that this article will be beneficial since the advancement of engineering education is strongly influenced by challenges and opportunities and anticipated future trends. Despite numerous challenges, engineering education is generally strong and the outlook for engineering education is bright.

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References


