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A THREE-DIMENSIONAL ENGINEERING CURRICULUM

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Abstract–This paper examines the recent developments affecting engineering education. The introduction of ABET 2000 criteria, the proliferation of engineering fields, and the changes in the characteristic of engineering teams are considered. It concludes that the traditional engineering curriculum, which is organized almost exclusively along the *fields* of engineering, is no longer capable of producing engineers for the twenty-first century, and therefore proposes a three-dimensional engineering curriculum, which is based on *function* and *employment sector*, in addition to the *field* of engineering. Philosophically, this proposed 3-D curriculum shifts engineering education from knowing to doing, from fragmentation to integration, and from convergence to divergence. On the practical level, the strength of the proposed 3-D curriculum lies in it being flexible, adaptable, diverse, and resource-sensitive. The diversity of possible programs resulting from the added dimensions enables engineering programs to develop a niche market, which has become an essential survival strategy.

Key words : Engineering Education, Curriculum, Higher Education, Teaching, Accreditation

INTRODUCTION

There is a major educational reform movement at all levels and areas of education in Korea. The examples of large-scale changes taking place at the level of higher education are the consolidation of academically related departments into schools to promote multi-disciplinary activities, and the designation of "research graduate schools" to enhance national research capability. These structural reforms are accompanied by measures aimed at increasing academic productivity and strengthening institutional accountability. For example, teaching evaluation, faculty evaluation, merit-based salary, and tenure-reviews are either being implemented or under serious consideration. Some universities are experimenting with the concept of shared governance and with the corporate-style administration, significantly altering the relationship between faculty and administration. The concept of "customer satisfaction" is allowed to permeate into the lexicon of campus politics and debates, affecting the relationship between faculty and students.

Strong initiatives are also evident in the area of curriculum reform. While there is a lively debate between the "revolutionist," advocating major overhaul, and the evolutionists, preferring a series of incremental changes, there seems to be a consensus that the current curriculum is woefully inadequate in preparing engineers for the future. The purpose of this paper is to propose an alternative to the traditional engineering curriculum, which is defined exclusively by the fields of engineering. It proposes an innovative, three-dimensional engineering curriculum that is based on the *field*, *function,* and *employment sector* of engineering.

The evidence submitted in support of a 3-D curriculum is based on the socio-economic trends in the US. However, it is important to realize that an educational reform movement is not unique to a particular nation. The arrival of Information Age has fundamentally changed the rules of game for all nations, and the very survival of a nation now depends on the productivity of its knowledge-workers [Druker, 1993; Naisbitt, 1990, 1996; Thurow, 1996; Toeffler, 1990]. Therefore, it is clear that the context and essence of the curriculum designed for engineering schools in the US is generally applicable to those in Korea.

THE TRADITIONAL ENGINEERING CURRICULUM

The traditional engineering curriculum conjures up an image of either the letter T or a funnel [Gaff et al., 1997]. The top horizontal line in the letter T represents the breadth in fundamentals while the vertical line signifies the depth of knowledge. Similarly, in the funnel imagery, the engineering students begin with a wide perspective and then progressively narrow the viewing field to a tighter focus area. In either case, the direction is from general to particular, the method is convergence, and the result is specialization.

Typically, an in-coming student is accepted into a specific department bearing the name of a *field* of engineering, such as mechanical engineering, chemical engineering, electrical engineering, or civil engineering. The student is required to take

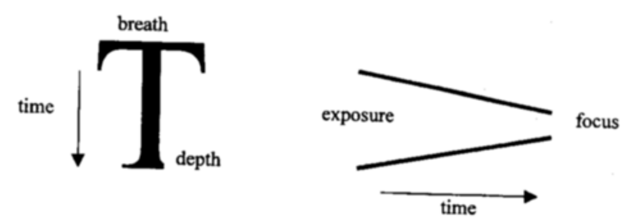

Fig. 1. Two images of the traditional engineering curriculum.

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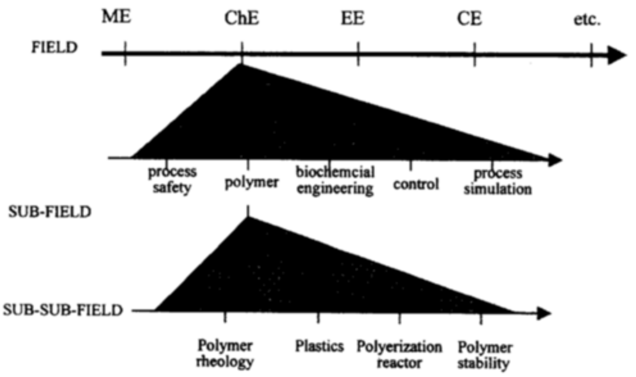

Fig. 2. An example of one-dimensional curriculum based on the *fields* of engineering.

general foundation courses during the first two years, followed by a series of in-depth technical courses during the later years. The technical courses are usually a collection of specialized sub-fields, and a cluster of these technical courses may be organized into a minor or an option. For example, a mechanical engineering department may offer options in the sub-fields of energy, manufacturing, controls, and dynamic systems. The option in energy may be composed of courses in energy conversion, combustion, gas turbines, and HVAC, each of which is a sub-field within the field of energy.

A similar sub-divisioning by field appears in other engineering programs. For example, the advanced courses offered by a chemical engineering program may be grouped into polymer materials, environmental engineering, biochemical engineering, process simulation and control, process safety, and process analytical chemistry. The option in rheology may in turn be composed of technical courses in rheology, plastics, polymerization reactor, and polymer stability. In summary, the traditional engineering curricula are divided and sub-divided exclusively according to the *fields* of engineering, as shown in Fig. 2.

This curriculum is geared to producing engineers who are very knowledgeable in a particular field of study. But, as explained in the following section, this curriculum is not suitable in an era characterized by information explosion.

THE IMPETUS FOR CURRICULAR REFORM

1. Engineering as Defined by ABET 2000

The most significant development in engineering education in recent years is the introduction of a document called ABET Engineering Criteria 2000, which outlines the accreditation criteria for the year 2000 set forth by the Accreditation Board for Engineering and Technology (ABET). The newly formulated ABET 2000 criteria is having a profound impact on engineering education community because the new criteria is radically different from the previous one.

According to ABET [1997], "it is the responsibility of the institutions seeking accreditation of an engineering program to demonstrate clearly that the program must demonstrate that their graduates have the following abilities" :

Program Outcome and Assessment

(1) an ability to apply knowledge of mathematics, science, and engineering.

(2) an ability to design and conduct experiments, as well as to analyze and interpret data.

(3) an ability to design a system, component, or process to meet desired needs.

(4) an ability to function on multi-disciplinary field.

(5) an ability to identify, formulate, and solve engineering problems.

(6) an understanding of professional and ethical responsibilities.

(7) an ability to communicate effectively.

(8) the broad education necessary to understand the impact of engineering solutions in a global and societal context.

(9) a recognition of the need for, and an ability to engage in life-long learning.

(10) a knowledge of contemporary issues

(11) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

There are several observations to be made from the ABET 2000 criteria. First, only five out of eleven objectives are explicitly addressed by the traditional curriculum. They are objectives 1, 2, 3, 5, and 11. The remaining six address the "soft" skills and are usually not considered to be the primary objectives of an engineering curriculum. These secondary objectives are often believed to be acquired through the general education component of the curriculum. However, ABET now demands that these "soft" skills be incorporated into the curriculum on an equal level as the "hard" technical knowledge and skills.

Secondly, the words *use*, *apply*, *analyze*, *formulate*, and *interpret* are used throughout the criteria. These are so-called "action-oriented" words. That is, engineering is now defined in terms of what engineers *do* instead of in terms of what they know. This mirrors the concise and perceptive contrast between scientists and engineers as given by the Encyclopedia Britannica : "The function of science is to know, while that of engineering is to do." Given the fact that many introductory textbooks on engineering generally quote ABET's definition of engineering [Wright, 1994; Eide, 1986], this change in emphasis from the subject matter (field of study) to the primary work activities (function) represent a major paradigm shift.

Thirdly, the deliberate choice of these words is pedagogically profound because these words reflect Bloom's Taxonomy, which categorizes educational activities according to six hierarchical educational objectives, as shown Fig. 3 [Goetz, 1992; Ozman, 1990]. It seems that ABET is no longer satisfied with the activities aimed at the lowest levels of educational objectives--knowledge and comprehension--but is promoting the activities at higher levels--namely, application, analysis, synthesis, and judgment.

In summary, ABET 2000 is demanding that engineering education be accountable for a greater number of goals at a higher level of educational outcome. The difficulty in satisfying these requirements with the traditional curriculum is that it is already

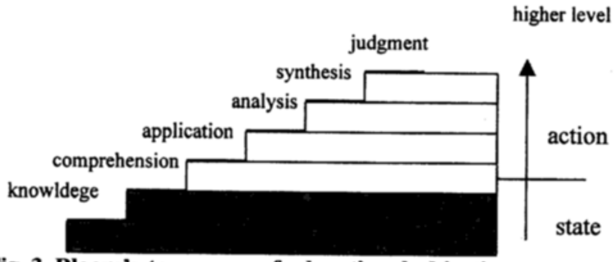

Fig. 3. Bloom's taxonomy of educational objectives.

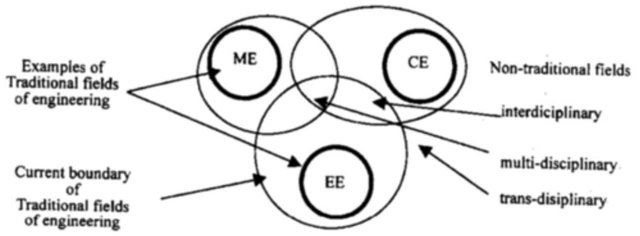

Fig. 4. The boundary of engineering fields.

too full, leaving no room for the inclusion of any additional material.

2. Engineering Fields are No Longer Mutually Exclusive

The second driving force for educational reform is the proliferation of academic fields. When engineering education first became formalized, the various fields of engineering were finite and distinguishable from each other [Seeley, 1993]. For example, the field of mechanical engineering did not overlap with that of electrical engineering. These separate academic fields were organized into administrative departments. However, over the ensuing years, the fields of engineering have expanded and outgrown their traditional boundaries. The fields start to overlap with each other as shown in Fig. 4. To accommodate the growth in these inter- and multi-disciplinary fields, some of them have gained independence and become departments with distinct curricula. In most cases, however, options and minors were created within the domain of the traditional departments. The net result is a further refining of engineering curriculum by engineering sub-fields (refer to Fig. 2).

The overlapping sub-fields represent the areas where the cutting-edge and critical technologies frequently emerge. Hence, it is likely that engineering curriculum will continue to be subdivided even further. However, the issue of resources--namely, how many options a department can afford to offer--will make this division of engineering curriculum by academic fields unsustainable.

3. Changing Composition of the Engineering Team

The third major driving force is the increasing dependency of society on technology, with the accompanying increase in the demand for a technology-savvy workforce. This changing social context has two immediate consequences on engineering. One is the proliferation of technology programs other than engineering, effectively changing the character of engineering teams [Wright, 1994]. An engineering team now may include the graduates from 2-year and 4-year technology programs, technicians of varying training, and craftsmen. The role of an engineer as the leader of an engineering team has always been a part of their job description. But, it is now one of the most importance aspect of the job function.

	The Engineering Team
Engineer	Conceptual design Research Project planning Product innovation System development **Supervision of technologists, technicians and craftsman**
Technologist	Routine product development Construction supervision Technical sales Hardware design and development Coordination of work force, materials, and equipment Supervision of technician and craftsman
Technician	Drafting Estimating Field inspection Data collection Surveying Technical writing
Craftsman	Use hand and power tools to service, maintain, and operate machines or products useful to the engineering team

The other consequence of a technologically complex society is the increased opportunity for engineers to be self-employed, either as consultants or entrepreneurs [NSF, 1993, 1995]. What this implies is that engineers can no longer be mere technologists; they now must be socio-technoligsts who can interface effectively among the members of the engineering team. The recent trend in concurrent engineering, total quality engineering, and down-sizing further contribute to the need for engineers to be effective communicators and adept in interpersonal skills. The one-dimensionality of the traditional curriculum, organized exclusively by the field of engineering, is not equipped to accommodate the specialization based on the function of engineering and to impart the diverse sets of skills which are dependent on a particular employment sector.

3-D CURRICULUM PROPOSED

In view of the difficulties encountered in the traditional curriculum, a three-dimensional curriculum is proposed. The proposed dimensions are the fields, the function, and the employment sector of engineering, as shown in Fig. 5.

The field dimension is the same as in the traditional curriculum. It addresses the technical sub-fields within each major discipline of engineering. Therefore, the proposed 3-D curriculum can be built on top of the existing curriculum with minimal modification.

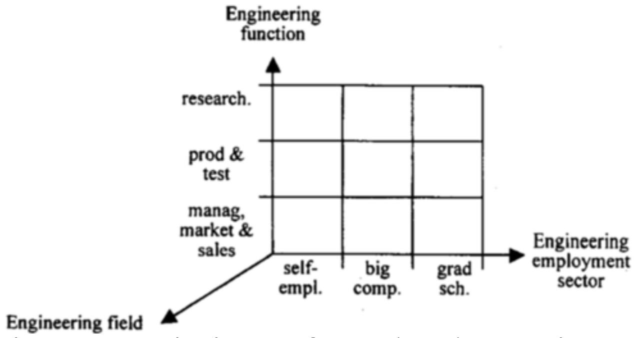

Fig. 5. A schematic diagram of three-dimensional curriculum.

The functional dimension addresses the primary work activities--research, development, production, inspection, management, marketing, sales, and consulting. These activities are listed in decreasing order of dependence on math and science. They are also in the order of less relevance to the content of a particular field of study. For example, research needs to be field-specific whereas sales need not be. This order is only a general statement and many exceptions are likely. For practical purposes, the functional dimension may be limited to just three options--R&D, Production, and Management, Marketing & Sales.

The engineering employment sectors are typically categorized as industry, self-employed, non-profit institutions, educational institutions, government, and military [NSF, 1995]. However, for the purpose of curricular identification, it is more meaningful to categorize them in three groups of big company, small company/self-employed/entrepreneur, and graduate school. Each employment sector has a distinct work environment and requires a different set of skills. For example, an engineer working in a large engineering team in a big company may find that specialized knowledge and technical skills to be of primary importance in the early stages of one's career. However, an entrepreneur needs to be a generalist, with a working knowledge of business and management complementing the knowledge in a technical field.

The matrix of nine options, obtained from three engineering functions and three employment sectors, forms the basic framework. It is not necessary that a department cover the entire matrix. The department may choose the options it wishes to offer, and the decision can depend on the nature and number of its student body, the facultys' expertise, and the departmental resources. For example, a department may include the "research" option if there are a significant percentage of students continuing on to graduate studies. The "research" option may then include projects in which senior students participate in on-going graduate research programs as assistants to graduate students, an activity strongly encouraged and promoted by the National Science Foundation. In contrast, for a department with less analytically oriented students, offering an option in "management, marketing and sales" may be appropriate. The courses relevant to this option may include engineering economics, accounting, technical writing, and the principles of marketing. This option can be equally valid for students who wish to continue on to a graduate program in management or to become an entrepreneur.

The total number of available options depends on the number of engineering sub-fields in a department. While the proposed 3-D curriculum substantially increases the number of options available to students, it is not necessarily accompanied by an increase in faculty teaching load. Some of the options, such as management, marketing and sales, cut across the fields of engineering (field-independent) and, therefore, they can be administered at the college level. This resource sharing will prove to be economical and efficient. In fact, the proposed 3-D curriculum makes economical sense only when the entire college is considered. The curriculum is "owned" by the college with much of the options shared by the departments. Only the field-specific options are to be "controlled" by the departments.

In the proposed 3-D curriculum, students will be admitted into the college of engineering, and not into departments. They will complete a year of common curriculum of basic foundation of math, science, and introductory engineering. Then they will be enrolled into specific departments to take a year of field-specific engineering courses. Students will then be allowed to take as a specified number of options, as illustrated in Fig. 6. For many students, a combination of a field-specific option and a field-independent option may be desirable and adequate. A combination of two or three field-specific options may be advisable for the students who are interested in pursuing engineering graduate studies. Some field-specific options, such as mechatronics and material processing, may be offered jointly by two or more departments.

CONCLUDING REMARKS

The traditional engineering curriculum is organized in terms of the fields of engineering. An engineering field is further divided into sub-fields and, ultimately, senior level technical courses offered by a department reflect the research interests of the faculty in the department. That is, a curriculum may be unwittingly designed to train the students for a research career, which is only one of many primary work activities (functions) of engineers. Recent research results clearly show the absurdity and danger of an ill-designed curriculum [Gardener, 1993; Steinberg, 1996]. Students who are not analytical may still be very creative, and yet they become discouraged from pursuing an engineering career because of the analysis-heavy engineering curriculum [Lumsdaine, 1993].

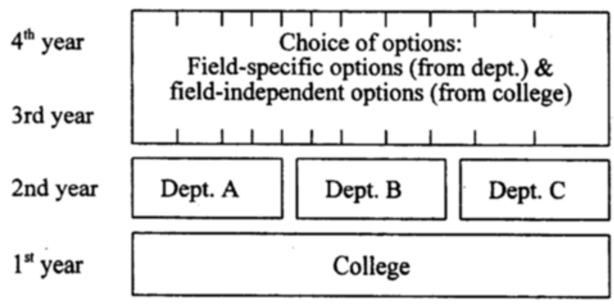

Fig. 6. A schematic time line of the 3-D curriculum.

The proposed 3-D curriculum offers several advantages. First, the diversity of options offered to students will allow them to pursue a career that best fit their ability and preference [Csikszentmihalyi, 1975]. Second, it is a curriculum that can help dismantle the departmental walls, which is the traditional source of turf-wars and parochialism. The joint operation of options will promote the culture of cooperation, while the wide-open enrollement policy will instill a sense of competition. This balanced environment of cooperation-competition is precisely what is needed for a university to be successful in the coming millenium. In fact, such an environment is ideally suited for the development of multi-disciplinary studies. Third, engineering schools can develop niche market identifiable by the options emphasized in their programs. The diverse options make it easy for engineering schools to be distinguishable from each other. Fourthly, it does not need any additional resource. The proposed 3-D curriculum is adaptable to the existing resources and flexible to the changing demands. It is responsive to the characteristics of the student body and faculty interest. Finally, its implementation is not going to be disruptive. Considering the fact that over two years of traditional engineering curricula are already identical (general education and first year components), this proposal is less about overhauling the existing curricula than about overhauling the way we *view* the curricula.

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