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Abstract— It is a global trend that those engineers who are proficient with the principles of business and management are rewarded with leadership roles. With the growing interdependence between technology, industry, economy and society, more opportunities will be available for engineers to exercise their potential as leaders, not only in business but also in the nonprofit and government sectors.

In this paper, the following questions are addressed: What does it mean for engineers to have business and management competency? How can engineering schools prepare their students to attain the type of business and management competency demanded by industry? The analysis presented in this paper addresses the above questions in the following ways. First it defines the meaning of business and management competency for engineers. Second, it offers a minimum learning criterion for the business and management competency of engineers and a set of three learning outcomes of engineering management education. Third, this paper shows the results of an industry demand survey for engineering management education as well as provides a review of the global educational trends in this field in the U.S., Japan and Korea. Finally, the leading examples and lessons learned from engineering management education at Yonsei University are presented, and recommendations are made.

Keywords- *engineering management; business competency; learning outcomes; accreditation*

I. INTRODUCTION

It is a global trend that those engineers who are proficient in the principles of business and management are rewarded with leadership roles. Being able to understand both advanced technology and its corresponding management strategy is the key to securing a competitive advantage in any high-tech firm or industrialized nation. With the growing interdependence between technology, industry, economy and society, more opportunities will be available for engineers to exercise their potential as leaders, not only in business but also in the nonprofit and government sectors. Policy decisions in a technology-driven society will require the attention of leaders who understand the strengths and limitations of science and technology and their impact on society. What engineers design becomes a core component of the critical network of engineering systems, which affect physical, human, and political infrastructures. New levels of sophistication will be

needed of engineers as decisions that define priorities and objectives for a community, region, or nation should be viable not only technologically and economically but also socially and environmentally [1].

In this context, it is now indispensable for engineering schools to equip their students with management skills and business leadership. However, current engineering management education is separately or only partially offered outside of traditional engineering curriculum. A survey in Korea shows that engineering students evaluate their undergraduate engineering education as only 50 out of 100 on a satisfaction scale. A major reason for the low satisfaction level is the impractical engineering education they received. The contents of the coursework were only remotely related to the real-world business problems that the students had to face upon graduation. Furthermore, the students felt that they needed to have more business and management competency in day-to-day corporate operations [2]. In order to meet this student demand, engineering management education should be better integrated with exiting engineering curriculum [3]. On the industry side, a majority of employers feel that educational support is currently insufficient for the enhancement of students' and their employees' business and management aptitude [4]. Engineering management curriculum must become better aligned with industry needs.

Designing an engineering management curriculum to meet the needs of students and employers requires an understanding of modern engineering work and the type of business and management competency expected of engineers. Also important is a well-defined framework to evaluate the success of the engineering management curriculum and continuous improvement of the learning contents and methodologies. Therefore, in this paper, the following questions are addressed: What does it mean for engineers to have business and management competency? What are the learning outcomes of engineering management education? How should one measure success in the proposed learning outcomes? Examining these questions will provide insight into prioritizing the business and management course contents that should be integrated with traditional engineering education and enhancing the learning achievement measured against the learning outcomes.

The analysis presented in this paper addresses the above questions in the following ways [4]. First it introduces the concept of business and management competency for engineers. Second, it offers a minimum learning criterion for the business and management competency of engineers and a set of three learning outcomes of engineering management education. Third it uses this criterion to establish a typology of emerging methods to support business and management learning for engineering students. Fourth, it introduces an engineering management curriculum of Yonsei University, as an example of a type of education experience that is expanding globally. Finally, the paper offers a test application of the learning criterion and learning outcomes by using them to conduct and present summative assessments of student learning in the Engineering Accounting course at Yonsei University, and to discuss the strengths and limitations of the current curriculum.

II. BUSINESS AND MANAGEMENT COMPETENCY FOR ENGINEERS

A. *What Engineers Do in Today's Workplace*

Science and technology are a source of product and service innovation and economic growth. Engineers apply the principles of science and mathematics to develop solutions that satisfy the technological and economic constraints of engineering designs. Their work transforms scientific discoveries into commercial applications that meet societal and consumer needs.

Engineers perform a number of tasks. They conduct research and development (R&D) in order to discover new technologies and apply them to various engineering systems and processes. Engineers are concerned with the design, production and operation of new engineering devices. Many engineers are engaged with new product development. In so doing, engineers must consider several factors. For example, they need to: precisely specify the functional requirements of a new system, design and test its components, integrate the components to produce the final design, and evaluate the design's overall effectiveness, cost, reliability, and safety.

In order to make sure the new systems meet various technological and standards, they conduct testing, which occurs in all stages of R&D and production. In addition, many engineers work in production or maintenance as they supervise production operations, determine the causes of component failure, and test the quality of manufactured products. Engineers also estimate and manage the time and cost to complete projects. Sales and marketing professionals work closely with engineers to assess user requirements and incorporate them into new products and services. Engineers are concerned with the economic, social, and ethical aspects of new products and services. Some experienced engineers are placed in management positions where their engineering background helps them examine technical aspects of a product and assist in planning its installation or use. Such engineers with managerial responsibility oversee all the tasks listed above performed by individual engineers and teams [5].

In most projects, engineers work in teams, whose size range from a few to hundreds of people, on a complex problem, such as designing computer chips or an aircraft. Teams usually include non-engineers such as technicians, marketing and service professionals. The team leader is responsible for communicating the progress and has to make sure that all of planning, developing, testing, and building is carried out correctly. In this regard, engineers must be good at planning so that money and time are spent efficiently on projects [6].

Because engineering work spans over all aspects of product planning, development, production, and even some degree of marketing, engineers must have competency not only in technical disciplines, but in areas of business and management. In particular, engineers must have an economic mind with which to view their engineering designs. Because of limited material, monetary and human resources, engineers are asked to maximize the technological performance as well as the economic efficiency of their solutions. If economic efficiency is ignored, engineering solutions often do not have practical value for the consumer market. To achieve economic efficiency, engineers must make strategic decisions including the purchase of capital equipment, target costing of new products and services, and investment sizing of engineering projects.

B. *Maintaining the Integrity in Today's Workplace*

Science and technology are a source of product and service innovation and economic growth. Engineers apply the principles of science and mathematics to develop solutions that satisfy the technological and economic constraints of engineering designs. Their work transforms scientific discoveries into commercial applications that meet societal and consumer needs. The above discussion illustrates the importance of both technical and non-technical knowledge and skills for engineers. Among non-technical skills, the business and management competency of engineers cannot be over-emphasized in today's organizations. In 2007, over 50% of newly appointed executives in large Korean enterprises held engineering or science degrees [7]. Government is broadening opportunities for engineers and scientists to hold public service positions because technical knowledge is essential in many public sectors, including: health/medical services, energy/environment, transportation, communications, agriculture/fisheries and national defense [8]. Companies also look for interdisciplinary knowledge of both technology and management even when hiring R&D personnel [9]. These facts clearly demonstrate the ever increasing demand for science and engineering professionals with excellent management skills in this new economy [10].

C. *Yonsei Engineering Management Curriculum*

Drawing from this industry demand, Yonsei University College of Engineering developed an Engineering and Technology Management (ETM) curriculum to enhance the business and management competency of engineering students. To define the ETM curriculum, an analysis was carried out to describe the strengths and weaknesses of current engineering students in terms of their aptitude, skills and knowledge. Based on these and an industry survey,

engineering management education should focus on teaching the following abilities: economic analysis skills, strategic mind for product development and marketing, leadership and professionalism, and organizational and human resource management skills. These skills are grouped into three areas: 1) corporate management, 2) industry and economy, and 3) strategy and leadership, so that engineering management courses could be designed for each area. Table 1 shows seven ETM courses developed through this process. In the corporate management area, Technical Human Resource Management is offered to enhance students' understanding about the strategic management of organizations and human resources (scientists and engineers in particular). Engineering Accounting combines traditional financial accounting with cost accounting for engineers and provides engineering students with a fundamental understanding of the economic impact their R&D activities have on profit-making. Engineering Economics, which mainly addresses the economic valuation of technology and engineering systems, is offered in the industry and economy area. Techno-Leadership and Entrepreneurship is a course for the strategy and leadership area that sculpts the mind of a leader and entrepreneur to create new value in corporate and government organizations.

These courses are created to cultivate engineering students' aptitude, skills and knowledge in areas where they have weaknesses and industry demands are strong. They are electives integrated with engineering accreditation so that students can take up to two courses from the ETM curriculum during the sophomore to senior years. With this curriculum, Yonsei University, a leading engineering school in Korea, has been offering seven ETM courses for over 800 undergraduate students every semester. An increasing number of engineering schools in Korea are offering engineering management courses as part of their core electives. For example, Ventures and Patent Strategy is the most widely-taught subject in Korean engineering schools, including KAIST and Seoul National University [11].

Table 1: Engineering and Technology Management (ETM) Course Development

<i>Curriculum Areas</i>	<i>ETM Courses</i>
Corporate Management	Engineering Accounting
	Technology and Product Marketing
	Technical Human Resource Management
Industry and Economy	Engineering Economics
	Economic Trends and Business Opportunities
	Techno-Leadership and Entrepreneurship
Strategy and Leadership	Ventures and Patent Strategy

III. A LEARNING CRITERION FOR BUSINESS AND MANAGEMENT COMPETENCY

Drawing on the discussion of the previous sections, the proposed learning criterion for the business and management competency of engineering students is as follows:

Through course instruction and participation, students will acquire the knowledge, ability, and mindset to design economic engineering solutions efficiently and effectively with market and customer orientation.

Learning criteria are broad statements that guide the development of learning outcomes, which then guide the creation and assessment of courses and curricula that are designed to help students satisfy the criteria [12]. The words economic and efficient mean minimizing resource waste or cost input while meeting the target goals for scheduling and performance. Unlike the traditional cost-plus pricing method where materials, labor and overhead costs are measured and a desired profit is added to determine a selling price, an acceptable price for a new product or service is determined based on market information. Then, a target cost is the maximum cost that can be incurred on a product while the firm can still earn the required profit margin given the particular selling price. Thus engineers should be able to reduce the overall cost of a product over its entire life-cycle. Engineers also need to view the financial statements of their company and determine how the engineering division could help improve the financial performance of the company.

The word effective is closely tied to the capability to manage engineering teams successfully. Engineers must communicate with all the stakeholders involved in a project as to what actions are to be taken, by when and how much money can be spent on each activity. The engineers and related members get together regularly throughout the project to check the progress and to deal with any issues that may come up. Thus good project management, which also necessitates leadership and strategic employment of technical human resources, is the key to success in any engineering work.

Finally, market and customer orientation leads to the capability to design new systems to meet the needs of the customers and to have market power in order to generate significant revenue. Engineers should care about how new products and services will be marketed to target customer groups and increase sales. Engineers should also utilize their R&D results to generate revenue in a variety of other ways. The revenues sources include not just final products and services but also patents, licenses and other interim results of the R&D work. In today's open innovation era where market and customer groups quickly expand as firms look to advance their technology through the use of external ideas and knowledge [13], it is vital for engineers to seize every opportunity to make profits from their R&D work. The proposed learning outcomes for the business and management competency of engineers are:

1. Students will demonstrate substantial knowledge of the business operations (R&D, manufacturing, and marketing) as well as financial data (revenues, costs, and profits)

2. Students will demonstrate substantial ability to manage R&D teams, analyze customer needs and apply economic analysis.

3. Students will display a mindset to care about efficiency and value maximization in R&D work and to continue to make the engineering solutions evolve to fit the market demands.

The learning outcomes point to the importance of learning about delivering innovative engineering solutions efficiently and effectively and linking engineering work with market demands. The first component of the criterion and proposed learning outcome focuses on knowledge. A successful learning experience in business and management enables students to gain a factual understanding of how engineers in the real world deal with non-technical issues such as managerial, financial, and marketing issues and the ways in which such non-technical considerations impact their engineering work.

The second component of the learning outcomes is ability. An engineer with business and management competency is someone who has progressed beyond “awareness skills” to achieve “process skills,” which combine the new form of knowledge into day-to-day practices of engineering work [14]. The process skills, which are gained through practice, indicate the ability to apply various methods of economic engineering design and organizational management skills in engineering work.

The third component/outcome is mindset, which is more difficult to identify and assess, yet it is as equally important as the previous two. The term, “mindset” does not indicate inherent features of character or personality, but refers to learnable tendencies or patterned actions that are observable by others [13]. It is the mind to treat engineering work as an integral business function and an object of management in order to create winning products and services in the market. As a result, engineers gain a macroscopic view on all corporate functions where engineering work is aligned to meeting business goals.

The Accreditation Board of Engineering and Technology (ABET) provides only a general program outcome related to the business and management competency of engineering students. One of the ABET program outcomes states, “Graduates have a respect for diversity and a knowledge of contemporary professional, societal and global issues [15].” The Accreditation Board of Engineering Education in Korea (ABEEK) realized the need to make this statement more specific toward the non-technical competency of engineering students as it says, “Graduates have a broad education which is necessary to understand the impact of engineering solutions in a global and societal context...knowledge of contemporary issues in the society, economy, environment, and law [16].” However, neither one clearly states the competency in business and management for engineers.

In this context, it is now necessary to articulate what business and management competency is required of engineers. The key element in this learning criterion is the descriptive image of engineers who bring out innovative engineering solutions in the most efficient and effective way with market and customer demands in mind. The learning outcomes accept the view that acquiring knowledge and experience in business operations, financial analyses and technology management skills leads to the achievement of the business and management competency required of engineers. The engineers with business and management competency then design products and services that best respond to customer needs and therefore maximize the probability of success in the market.

IV. PRELIMINARY ASSESSMENT OF ENGINEERING MANAGEMENT EDUCATION

The first step for engineering students to gain competency in business and management is to have concrete knowledge about business operations and experience in financial analyses and technology management skills. As displayed in Table 1 Yonsei University’s College of Engineering developed an Engineering and Technology Management curriculum with 7 foundational courses based on industry demands and the strengths and weaknesses of engineering students. The subject categories were corporate management, industry and economy, and strategy and leadership. This section introduces a preliminary assessment result of the learning outcomes of the Engineering Accounting course, which teaches students the principles of accounting in the ways engineering work is related to managerial and cost accounting and how corporate functions act together from financial perspectives.

A. Course Outcomes

By introducing the fundamentals of accounting and accounting issues that are related to corporate management and R&D work, the Engineering Accounting course helps students gain the knowledge and skills to analyze financial statements, manufacturing costs and tax issues from the engineer’s perspective. Three learning outcomes of the course are:

1. Students will demonstrate substantial knowledge of the fundamentals in accounting including the meanings of financial accounts and costs and interpretation of financial statements.

2. Students will demonstrate an ability to analyze and recommend ways to improve the financial performance of a company using various parameters measuring the financial outcomes of R&D and other business operations.

3. Students will demonstrate a mindset that realizes the importance of minimizing cost from R&D planning stages while maximizing the value of new engineering designs. They are conscious of meeting customer demands and aligning engineering work with the business goals of the company.

These outcomes are more specific to the topics of Engineering Accounting; therefore, they deviate somewhat from the learning outcomes introduced in Section III. The

reason for this is that Engineering Accounting is only one of the 7 courses in guiding engineering students toward business and management competency. Fully attaining the outcomes presented previously is not easily accomplished by taking a single course in each topic, but the combination of the 7 courses is designed to equip engineering students with fundamental competency to deal with business and management issues that arise in engineering work. Rationalizing this leads to the more operative learning outcomes:

- Learning Outcome 1: In achieving this outcome, students come to understand accounting as a business language that expresses the state of the company through financial data expressed in certain standard formats. They also understand that accounting is a way to provide financial information to various stakeholders of the company, which engineering students have rarely thought about. The subject topics to help students achieve this first outcome include the role of accounting in corporate management, reading financial statements, and costing of R&D projects.
- Learning Outcome 2: The second outcome develops the ability to analyze the financial performance of a company using various accounting parameters. Students get exposed to a number of financial statements of different companies and are asked to analyze them. Students also learn to analyze the break-even points for engineering projects, to assess the financial performance of the engineering division, and to make various business decisions such as outsourcing. They also get exposed to the methods of activity-based costing, target costing, and taxation for start-up companies.
- Learning Outcome 3: Achieving outcome 3 is probably the most difficult for students in one semester. To broaden the mindset of engineering students, it is necessary to expose them to as many real world issues as possible. That way, students will learn to see how engineering work is related to broader areas in the company, economy and society. In Engineering Accounting, professionals (i.e. certified public accountants and accounting consultants) are invited at the end of the semester to tell engineering students about real world issues, why it is important for engineers to know accounting, and how engineers can proceed to business and management careers. The satisfaction level of such special lectures has been exceptionally high. The lectures of the invited speakers have had a positive impact on shaping the mindset of engineering students, and some engineering students even find a new career

opportunity that combines their engineering knowledge with business and management.

B. Course Outcomes

To date, Engineering Accounting has been taught in five consecutive semesters. Each semester, around 150 students from all engineering departments are registered. Sophomores make up around 50% of the class, and a good number of juniors and seniors also attend the course for academic credit. Formats include lecture/discussion in large classes as well as 100 percent online lectures to help students preview/review class materials. Thus in-class activities focus on the presentation of important concepts in depth as well as exercises with accounting problems and short business case studies. At the beginning of each class session, a short quiz is given to help students grasp the fundamental concept of the day. A web board is heavily used for informal writing with student responses posted through online threaded discussions, autobiographical statements, and dialogues. Formal writing has included research reports, in-class exams, and reflections assignments. In addition to the Engineering Accounting textbook, a couple of introductory books, one of which is a business novel that depicts a career progress of a novice in accounting, are given for students to read over the course of the semester.

C. Assessment

Formative class evaluations have been conducted every semester since Engineering Accounting was first taught, and revisions to the course have been made. However, the evaluation questions were only general to assess the program outcomes of ABEEK [16] as discussed above. The faculty members who were teaching the 7 ETM courses realized that a simple program outcome statement of ABEEK was not effective to assess the learning of the business and management competency of engineering students. Thus, the learning criteria and outcomes, as well as a new assessment framework, were designed in 2007 in order to assess the engineering students' learning achievement in business and management competency. The focus of this section is on the summative assessment conducted in Fall 2007 to evaluate the extent to which engineering students accomplish the three learning outcomes for business and management competency mentioned earlier. The summative assessment included three instruments that map across the learning outcomes: a short pre/post quiz to measure learning outcome 1, a term project to measure learning outcome 2, and a final survey/reflection to measure learning outcome 3. Data from the final survey/reflection also provide additional evidence for learning outcomes 1 and 2. In this paper, the students' responses to an end-of-semester survey in an Engineering Accounting class are shown. A core set of questions was used and several additional questions were asked of students to assess the effectiveness of textbooks and teaching methods used. Only questions on this survey that were relevant to course outcomes are discussed below.

The survey asks students to indicate their level of agreement with a set of statements. A high percentage of students either “agreed” or “strongly agreed” with each statement. Roughly 85 percent of 90 students agreed that they “gained significant knowledge from this course about accounting and its importance for engineering work.” 80 percent agreed that they are “better prepared through lectures and homework assignments to consider financial aspects in engineering work” and 78 percent agreed that they gained “critical skills to analyze the corporate financial performance and suggest ways to improve weaknesses.” Importantly, the survey asks students to assess how their mindset has changed upon completing the Engineering Accounting course. 78 percent of the students agreed that they have “increased interest and passion in engineering management disciplines” and around 80 percent indicated that “the special lecture contributed to both deeper understanding and change of attitude toward the importance of business and management competency of engineers.”

The student survey results support the findings for learning outcomes 1 and 2, but more importantly, they provide evidence for learning outcome 3, development of a mindset to regard engineering work as having to improve corporate financial performance while minimizing cost input. The reflections that one student wrote in the survey stated, “I had no knowledge about accounting but this course helped me not only learn the principles of accounting but have the mind of a CEO to view engineering work as a critical business function.” Another student noted, “This course is a must for all engineering students. I am now more confident to have the knowledge and business-oriented eyes necessary throughout my career as an engineer and a future CEO.” Similar reflections are gathered in every semester. This clearly indicates the success of learning outcome 3.

V. SUMMARY AND CONCLUSIONS

The descriptive image of an engineer with business and management competency is someone who can successfully manage the development of innovative engineering solutions in an efficient and effective way with market and customer demands in mind. Through course instruction and participation in such activities as case studies, design projects and internships, engineering students acquire the knowledge in business operations, economic analysis and organizational management skills, along with a strategic mind for product development and marketing.

Based on the lessons learned over the last two years, the ETM curriculum of Yonsei University is being improved. First, it is necessary to diversify and customize the ETM courses to respond to the needs of each industry sector and engineering major. For example, civil and environmental engineering students feel that an environmental management course will be valuable to them. For architecture and construction engineering majors, a course in large-scale project management is necessary.

In addition, course evaluations suggest that specialized tracks be developed where students can take advanced courses in a field of their choice. For the case of Engineering Accounting, students were very interested to learn more about product development and target costing as well as taxation issues related to new business ventures.

A number of students indicated the need for more problem solving and case studies. It is not possible, however, to cover all aspects of theories, problem solving and case studies in class. It may be effective to break the class into small groups to hold help sessions. In fact, the large class size has been consistently pointed out as an area in need of improvement. More instructors who are familiar with engineering work and have competency in a business and management discipline should be hired. Also, as indicated earlier, undergraduate-level case studies should be developed and provided online so that students can access them at their convenience to augment their learning. Also, a global network of engineering management education should be expanded through more frequent dialogues and open exchange of information.

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