TOWARDS PROBLEM-BASED ENGINEERING EDUCATION

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ABSTRACT

This paper presents problem-based engineering education (PBEE) as a new approach to engineering education that is based on the problem-based learning (PBL) philosophy. PBEE provides both a curriculum and a process in an educational format that is centered on the discussion and learning that emanates from an engineering based problem. The PBEE curriculum will expose the student to carefully selected and well designed problems that demand from him acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies and team participation skills. The process is typical to the systematic approach used for resolving problems that are encountered in engineering career.

The paper outlines a modular structure for the implementation of PBEE concept. The modular structure consists of three phases: pre-engineering, engineering science and practice, and professional skills.

Keywords: *Engineering education, undergraduate engineering curriculum, problem-based learning, problem-based engineering education, factory-aided engineering education.*

الملخص

يواجه الأسلوب التقليدي للتعليم الفني والهندسي الكثير من الصعاب والتحديات التي تحتم السعي الحثيث إلى تطويره لكي يواكب متطلبات سوق العمل. و في هذا السياق تقترح الورقة الحالية أسلوب التعليم المبني على المسائل للتغلب على المشاكل التي تواجه التعليم الفني والهندسي. إذ أن هذا الأسلوب يساعد الطالب في فهم العلاقات المتداخلة بين مختلف العلوم الهندسية المضمنة في البرنامج الدراسي. ومن أهم مزايا التعليم المبني على المسائل جعل الطالب محوراً للعملية التعليمية وتناول مسائل هندسية واقعية لتطوير المهارات والتطورات المطلوبة لمعالجة مثل هذه المسائل.

يمثل التعليم المبني على المسائل نهج متكامل للتعليم يشتمل على منهج وأسلوب. يتكون المنهج من مسائل اختيرت وصممت بعناية بحيث يحتاج تناولها من المتعلم إلى حد أدنى من المعرفة ومقدرة على حل المسائل والتعليم الذاتي ومهارات المشاركة ضمن فرق العمل. أما الأسلوب المتبع في التعليم المبنى على المسائل فهو يماثل الطريقة المنهجية العامة التي تستخدم في حل المسائل والمشاكل والتحديات التي تواجه المهني أثناء حياته المهنية.

تقدم الورقة مخطط هيكلي لمراحل منهج التعليم الهندسي المبنى على المسائل, حيث يتكون المنهج من ثلاثة مراحل: مرحلة ما قبل الهندسة و مرحلة العلوم الهندسية و الممارسة ومرحلة المهارات المهنية. و تشتمل كل مرحلة من هذه المراحل على عدد من الموديولات التي تتكامل مع بعضها البعض لتغطية أهداف المنهج.

1. INTRODUCTION

Employers complain that most of the university students are graduating without the right type of skills for the modern market place, which is one amongst the key criteria of the engineering realm. The major complaints about engineering graduates are graduate's poor written and verbal skills, their inability to problem-solve and their difficulties in working collaboratively with other professionals. Being cosseted in academic ivory towers, they lack an understanding of commercial realities and are frequently unprepared for industrial life. To overcome this, continuing professional development (CPD) programs are developed by universities and technical colleges in collaboration with industry for engineering graduates and post-graduates [David, 2001] and [Suliman, 2001].

But it seems that the CPD programs are still not satisfying the ambitions of the industry that has lead to the emergence of in-house, corporate universities of technology such as Burger King University, Xerox Document University, Home Depot University and others. This emergence, besides being an opportunity and a challenge to traditional universities, is shaking up the way both industry and universities think about their roles. On the one hand, it reflects an enormous growth in demand for continuing education and a chance for universities to forge new partnerships with industry that are placing more value than ever on an educated work force. On the other, it poses a direct competition in an arena where universities have had a monopoly for long time.

All of the above implies that the traditional approach of engineering and technology education has to be confronted with a real challenge, and genuine endeavors for its development are a must. Some speculations were posed about the **"educational factory"** or **"factory aided engineering education"** in an analogy to the **"educational hospital"**, an approach that is successfully realized long time ago in medical education [Suliman, 2001].

Factory-aided Engineering Education (FAEE) is not a completely new concept, because as mentioned above relationships between industry and engineering schools exist already in the form of cooperation at varying degrees. However, what is new is that with FAEE philosophy the relationship between the two organizations will be casted into formal partnership. This definitely needs redefinition of the strategies and goals of the engineering education and ultimately it will emerge into highly effective educational institutions armed with the academic knowledge and practical know-how that satisfy the industry and community needs. Actually, FAEE is a very sound and logical substitute for the current move of the industry towards corporate universities of technology.

Adoption of FAEE definitely will be impaired with the traditional teaching methods of engineering and technology. It requires new teaching methods and styles. Problem-based learning (PBL) is a sound teaching style that will match FAEE and will enhance engineering education in general. It is a teaching style that has been incorporated as a curriculum component in a number of medical schools around the world. During the last two and half decades, many medical schools in the States, Canada, and few schools in the Middle East and India have introduced PBL into their curricula. Published reports show some evidence that PBL is at least as good as conventional curriculum [Russo, 1995].

PBL is a total approach to education including both a curriculum and a process. The curriculum consists of carefully selected and designed problems that demand from the learner acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies and team participation skills. The process replicates the commonly used systematic approach for resolving problems or meeting challenges that are encountered in professional career.

The context for learning in PBL is highly context-specific. It serves to teach content by presenting the students with a real-world challenge similar to one they might encounter in their future career. In other words, PBL is more inductive: students learn the content as they try to address a problem.

The successful introduction of PBL in medical education is a stimulant to explore the possibility of introducing PBL in curricula of engineering schools. Education wise, both medicine and engineering require a sound scientific background that can be covered in pre-medical and pre-engineering programs. It can be said that the nature of both professions is problem solving oriented but with different emphasis. In medicine, problems revolve around a common clinical scenario whereas the engineering problems revolve around a product manufacturing or service provision scenario. Analytical and operational knowledge of systems and subsystems are essential for practicing both professions since the knowledge of human body and that of production processes are based on system concept.

Furthermore, engineering aims at the welfare and prosperity of the community, this to be achieved there is always a challenge to be creative to introduce new products and new services. This requires abstraction and analytical capabilities, which are developed through a creative reasoning process. On the other hand, medicine aims at providing health care and improving quality of life, which in turn is achieved through developing an effective clinical reasoning process. The reasoning process used in both professions includes problem synthesis, hypothesis generation, and critical appraisal of available information, data analysis, and decision-making.

It can be stated that PBL can be adopted for engineering and technology education (problem-based engineering education, PBEE). The main objective of PBEE will be to enable the student to develop an understanding of the relationships between various disciplines in his/her program of study. It provides an opportunity to make the learning process student centered, to tackle a realistic engineering problem, and to develop intellectual skill and appropriate

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personal qualities. PBEE allows the development of the individual's time-management, teamwork, and communication skills, and require the use of initiative and judgment. Such a style will broaden the student's experience and develop his/her sense of responsibility and self-assurance.

2. CURRICULUM STRUCTURE OUTLINES

It is a fact that most universities currently over-teach engineering to students. Engineering courses are notorious for crowded timetabling and an emphasis on the learning of factual material at a highly advanced level across a large variety of topics. Although, the traditional lecture remains the most effective way to pass on large amounts of factual information to large groups of students, however, its emphasis on knowledge and amount of knowledge rather than understanding is a major drawback [Cross, 1986]. Careful redesign of engineering syllabi is essential to free the students from the restrictions of the lecture theatre and guide them towards exploration of advances in technology that have added more ever-changing subjects.

Due to rapid change in the technological advances, the range of disciplines that an engineer must grasp has grown dramatically with the increasing complexity of materials, products and services. No longer the engineer can relay exclusively on past-learned techniques, he must be able to understand and adapt to new experiences. Furthermore, it is unlikely for a graduate engineer to start his career in a specific job, rather he will have many different responsibilities to look after. Undoubtedly, there is no single degree program that imparts the breadth of experience needed in engineering today. Thus, **engineering curriculum should have an increased emphasis on understanding and reduced emphasis on the amount of the presented knowledge**.

Within the context of this paper, a modular degree scheme, with emphasis upon self-study rather than lecture, is proposed. The proposed curriculum is structured with the intention to educate students to be responsible for their own learning, to be communicators, adaptable, independent and have initiative. This will adequately prepare graduates for their career, and help them to deal with changes in their working environments.

The curriculum consists of twelve modules divided into three phases (Figures 1 and 2):

- Phase I extends for 12 months to cover the pre-engineering modules.
- Phase II extends for 24 months to cover the engineering science and practice modules.
- Phase III extends for 18 months to cover the professional skills modules (industry-based projects).

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2.1. Phase I: pre-engineering modules

A sound scientific background in the field of mathematics, physics and chemistry is essential for any undergraduate student planning for a degree in engineering. The pre-engineering module provides this requirement. The aims and objectives can be summarized in the following:

1. To introduce new learning style based on self-directed learning and developing problem solving abilities.
2. To develop the students' English abilities.
3. To develop a foundation in science, namely, mathematics, physics and chemistry, which will allow students to follow the engineering curriculum.
4. To develop the students' critical thinking abilities.
5. To introduce the students to humanitarian and social sciences that are related to engineering studies.

During the pre-engineering one-year period the students study Arabic, Islamic studies, English, Mathematics, Physics, Chemistry and Computer Science. The goal of this program is to prepare the students who are generally high school graduates for innovative engineering program in terms of knowledge, skills and attitudes, as well as for self-directed learning and problem solving. Furthermore, the program is designed to improve the student's ability to write, read, and understand English, which is usually the medium of instruction, and to understand the principles of communication skills, creative thinking and constructive analysis.

Module 1 (1st Semester I)

Subject	Credit hrs.
1. English I	3
2. Math I	3
3. Physics I	4
4. Chemistry	4
5. Arabic Studies	2
	16

Module 2 (2nd Semester II)

Subject	Credit hrs.
1. English II	3
2. Math II	3
3. Physics II	4
4. Computer Science	4
5. Islamic Studies	2
	16

2.2. Phase II: engineering science and practice modules

The subjects of this phase constitute the assimilative knowledge and convergent knowledge that are attained through reflective observation, abstract conceptualization and active experimentation. The subjects are taught within a problem-based, case-based and collaborative learning and reasoning environment. At this stage of engineering education, laboratory-learning experience is very essential for the accommodative knowledge, which is attained through active experimentation and concrete experience [Crosthwaite and Lee, 1994].

The aims and objectives of the engineering science and practice modules can be summarized in the following:

1. To strengthen the new learning style that based on self-directed learning, group learning and developing of problem solving abilities.
2. To develop a foundation in engineering sciences which will allow students to pursuit for a degree in engineering.
3. To further the students' critical thinking abilities.
4. To gain a better understanding of theoretical concepts, instead of seeing it as an academic exercises.
5. To develop students' integrative skills in analysis, synthesis and contextual understanding of engineering problems.

The engineering science and practice phase addresses the concepts and principles in a specific field of engineering in an integrated manner. This includes basic and advanced engineering science subjects in addition to engineering practice. The subjects are taught within a problem based and collaborative learning and reasoning environment. Any engineering profession aims at satisfying a need that can be exemplified by production of a product and/or provision of a service. Satisfaction of such a need evolves through an integrated multi-stage process involving design, production, operation and maintenance. Based on this fact six units are offered in the engineering science and practice phase, each unit includes between 8 to 14 problems with duration of one week per problem. The number of problems per module depends on the focus of the specific engineering discipline and the intended degree of specialization.

The units are designed such that the knowledge and skills needed for a later unit are more than those needed for an earlier unit. Thus, the starting unit of this phase covers the basic engineering concepts and principles, then key concepts are added-on unit by unit till the last unit, which integrates all the concepts of the previous units.

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- Unit 1: Basic engineering principle module (10 problems)
- Unit 2: Design module (10-14 problems)
- Unit 3: Production module (10-12 problems)
- Unit 4: Operation module (8-10 problems)
- Unit 5: Maintenance module (8 problems)
- Unit 6: Integrated module (10 problems).

Each unit comprises two learning activities:

1. Problem-based learning sessions
2. Laboratory-learning program.

Problem-based learning sessions

PBL is the main and repetitive educational activity comprised within each of the different units of this phase. The themes and intermediate objectives related to each unit are formulated by a unit committee, and included in a unit booklet. The unit committee chooses the appropriate problems, which address the objectives according to certain criteria, treatability, appropriateness for level, multi-stage coverage, and potential for learning basic engineering science and related professional skills.

One or two coordinators assigned to each problem, meet with an interdisciplinary group of resource people (academic and technical-staff) to decide on the specific objectives of the problem. The problem is formulated and resource faculty, reading material and references identified.

The students in each semester/year are divided randomly into small groups of eight to ten. A faculty tutor is assigned to each group to facilitate the learning process. Rather than being a "content expert" who provides the facts, the tutor is responsible for guiding the students to identify the key issues in each problem and to find ways to learn these issues in appropriate breadth and depth. Each week the students study one problem, which constitute the focus of learning, complex problems may extend over two weeks. The first tutorial focuses on identifying learning needs, which arise from the students attempt to analyze and solve the problem. Self- study is undertaken before the second tutorial, during which they share their learning with each other. The setup encourages an inquisitive and detailed look into concepts and principles contained within the problem. The time spent outside the group setting facilitates the development of skills such as literature retrieval, critical appraisal of available information and the seeking of opinions. Thus the students are more involved in, and responsible for their own learning.

Laboratory-Learning Program

At this stage of engineering education, laboratory-learning experience is essential for the accommodative knowledge that is attained through active experimentation and concrete experience [Crosthwaite and Lee, 1994]. This is achieved by introducing the students to a core of applied basic science skills, and technologies through the laboratory-learning program. The program extends throughout phase II of the curriculum, and is coordinated with the learning problems of the different units.

Introduction of multimedia technology to engineering laboratory work has the potential to greatly enhance the availability and uses that students can make of different learning experiences. Additionally the multimedia approach offers the advantage of integrating all the learning experiences within a total coordinated package. The use of interactive computer aided learning lessons and simulations that can be worked safely at the students' individual pace, in their own time and without the supervision needed for regular laboratory classes makes possible active experimentation and reflective observation in friendly environments.

2.3. Phase III: Professional skills modules

Industrial collaboration is vital for the formation of engineers who, by repeated exposure not only to new technology but also to problem encountered in the field, will begin their careers with an increased awareness of industrial aspects. Undergraduate courses should give students a true image of the engineer in industry: as an authority on technology, an innovator, a leader and a communicator. In other words, students need to acquire the analytical tools to assess risks and impacts, to perform life cycle analyses, and to solve technical problems, taking into consideration the economic, socio-political and environmental implications.

The inclusion of the professional skills modules into the proposed curriculum is driven by a number of specific difficulties that engineering education faces today. Engineering students are prepared for the needs of industry in an environment – classroom - organized and structured in very different ways than industry. Courses in engineering present information structured in terms of single disciplines. As a result of this structure, students often miss connections between various data and techniques that do not fit into that particular structure. Industry problems are usually met with cross-disciplinary techniques. Furthermore, engineering concepts are often taught in the abstract form. Students often have difficulty in understanding these abstract concepts as divorced from concrete examples. Finally, graduates are expected to work as a member of a team while classroom work is primarily individual.

The aims and objectives of the professional skills phase (industry-based project modules) can be summarized in the following:

1. To further strengthen the new learning style that based on self-directed learning, group learning and developing problem solving abilities.
2. To further the understanding of theoretical concepts.
3. To bridge the gap between the abstract and the concrete knowledge.
4. To further the students' integrative skills in analysis, synthesis and cross-discipline connections, and contextual understanding of engineering problems.
5. To prepare students for team working.

In this phase the industry is given the chance to take a really positive role, to device research projects to suit their specific needs as well as to play an influential role in students' development. By giving industry greater responsibility and involvement, the student gets to work on a real life project that has true industrial relevance and adds up to their experience a divergent knowledge dimension.

In this final phase of the undergraduate curriculum, students undergo supervised lengthy industrial training periods in related industries. The goal is to prepare the students to acquire knowledge, skills and attitudes which will enable them to identify, analyze and mange engineering problems in order to provide efficient and cost effective products and services to the community.

The Professional skills phase is designed to cover four projects of different emphasis with an average duration of four months each:

- Project 1: design focusing
- Project 2: production focusing
- Project 3: operation focusing
- Project 4: maintenance focusing.

By returning the emphasis for learning to the students, enthusiasm for the subject will be restored. In addition, more involvement with medium/long-term research projects and increased use of industrial collaborators will encourage career interest. Regular seminars by local consulting engineers are essential to provide a positive and realistic role model, encourage professional attitudes and often provide an insight into the human aspects of engineering. This is the efficient way to produce useful and competent engineers, capable of thinking on their own and making effective decisions.

3. CONCLUSION

A modular degree scheme is proposed that is focused on self study rather than the traditional lecture style. The curriculum is structured in such a way to educate students to be responsible for their own learning, to be communicators, adaptable, independent and to have initiative. This will adequately prepare graduates for their career, and help them to deal with changes in their working environments.

The modular structure consists of twelve modules. The modules of the pre-engineering phase provide the scientific background needed for any engineering degree. This phase is followed by the engineering science and practice modules that provide the student with the engineering knowledge including assimilative, convergent and accommodative knowledge. The final phase includes the professional skills modules, which furthers the accommodative knowledge and adds up another experiential learning dimension manifested in divergence knowledge.

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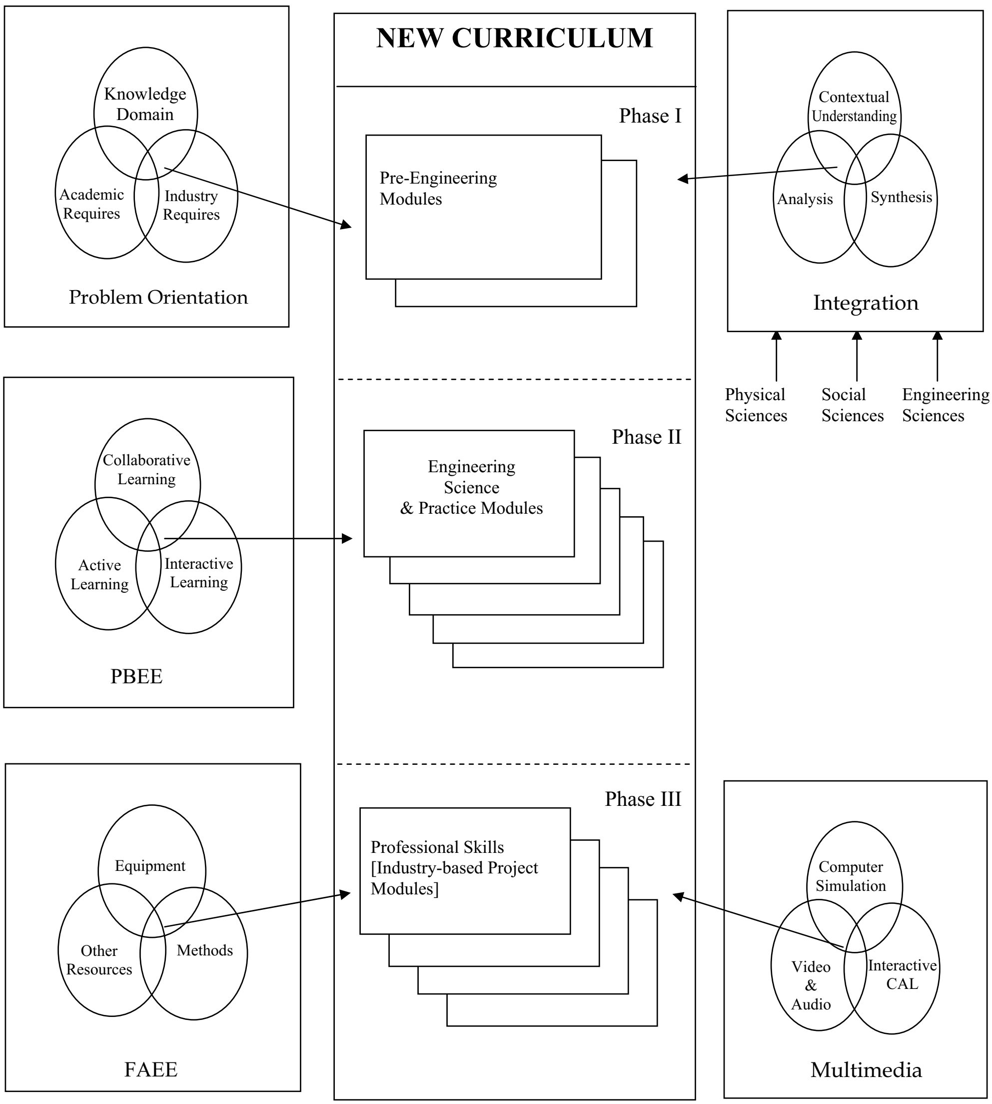
NEW CURRICULUM
Phase I
Pre-Engineering Modules
Phase II
Engineering Science & Practice Modules
Phase III
Professional Skills [Industry-based Project Modules]
Knowledge Domain
Academic Requires
Industry Requires
Problem Orientation
Collaborative Learning
Active Learning
Interactive Learning
PBEE
Equipment
Other Resources
Methods
FAEE
Contextual Understanding
Analysis
Synthesis
Integration
Physical Sciences
Social Sciences
Engineering Sciences
Computer Simulation
Video & Audio
Interactive CAL
Multimedia

Fig. 1.

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Year				Phase
	Pre-Engineering			
1	Semester 1 (16 credits)	Semester 2 (16 credits)		I
	Engineering Science and Practice			
2	Unit 1 Basic Engineering Module (10 problems)	Unit 2 Design Module (10-14 problems)	Unit 3 Production module (10-12 problems)	II
	Engineering Science and Practice			
3	Unit4 Operation Module (8-10 problems0	Unit 5 Maintenance module (8 problems)	Unit 6 Integrated Module (10 problems)	II
	Professional Skills			
4	Project 1 Design focus module (16 weeks)	Project 2 Production focus module (16 weeks)	Project 3 Operation (16 weeks)	III
	Professional Skills			
5	Project 3 Focus module	Project 4 Maintenance focus module (16 weeks)		III
Year	September → June			Phase

Figure 2: Curriculum map.

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