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Introducing Mechanical Engineering to Students in the Gulf Region*

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The design and implementation of introductory courses in engineering have been well documented in Western education, in the context of how engineering education practices must adapt to meet the needs of the twenty-first century. As Gulf students exhibit characteristic strengths and weaknesses, engineering education in this region faces additional, specific challenges that are associated with economical, social and cultural factors. This paper discusses the adaptation in the Gulf region of Western models of engineering introduced to entry-level students, and describes the strategy adopted at The Petroleum Institute to introduce mechanical engineering (ME) to sophomores. Significant blocks of time are devoted to broadening the students' understanding of the ME discipline and profession, fields, tools and practices. The traditional aspects of ME are concisely covered, enabling emphasis to be placed on the petroleum industry and the broader energy sectors, as well as modern and emerging applications of ME. The course structure and teaching methodology focus on developing key professional attributes identified by ABET, promote student involvement and utilize student strengths while tackling characteristic weaknesses in Gulf regional students. After three-semester offering and evolution of the course, it was found that motivated students could demonstrate excellent proficiency in what constitutes mechanical engineering in the twenty first century.

Keywords: Arab, education, engineering, mechanical, gulf.

INTRODUCTION

IT IS GENERALLY ACCEPTED that before entering an engineering programme, most students do not possess even a basic understanding of the engineering process and profession [1, 2]. This is more evident in engineering than in medicine or law, as everyday life generally offers more opportunities to interact with such professions. Thus, when high school students opt for engineering studies, this decision is based upon a perceived natural affinity towards the field [1], yet incomplete information [2].

Focusing on sophomore mechanical engineering (ME) students, the present authors have also observed that their perception of the profession and discipline can be significantly outdated. This can be explained in part by the pace of technological advance in the past decades, which has left society behind in terms of its understanding of the modern profession and awareness of its applications. Although the underlying principles of ME are essentially unchanged, the field of applications has expanded considerably [3]. Based on discussions with students and colleagues, the popular perception of ME today appears to be essentially captured from pre-1980s activities, symbolized by large-scale machinery and engines, and key products such as cars and aeroplanes. Applications that fall outside popular visibility remain unknown to the non-specialist. For example, the authors found that most of their sophomore ME students were unaware of the involvement of mechanical engineers in biomedical engineering, or of the existence of microelectromechanical structure (MEMS) sensors in cars, though commercialized in the previous decade, or in consumer electronics popular among the young generation.

The traditional approach to addressing this knowledge deficit has been to incorporate a review of the curriculum and the different branches of ME, as well as of the engineering process, in an introductory freshman course [4]. Typically, the teaching approach employed has been based upon traditional, in-class lectures. This introduction could eventually be complemented by more advanced special topics lectures on ME technologies at Junior or Senior level. However, recent trends in United States (US) engineering education are characterized by an inversion [5] and improved continuity of the curriculum with respect to design activities [6], which are now incorporated from freshman level onwards, rather than in senior year only, and by teaching methodologies that encourage student active participation [7]. Examples of introductory engineering courses in line with this strategy are discussed in [1, 2, 4, 8, 9]. There is evidence that pre-capstone design experiences can also improve freshman retention rates in the US [9], the decrease of which has been partly attributed to the traditional focus on mathematics and physics in the freshman year [1]. In this

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approach, an overview of ME technical subject areas and applications can be covered in the engineering science courses (e.g. thermofluids, mechanics and materials, automation and control), rather than in a traditional, dedicated introductory course [4].

Jones and Oberst [5] note that the US engineering educational model is attractive to many countries both for its qualities and the fact that it is an important contributor to the success of the technology-driven economy in the US. They also note a shift of engineering education in Europe closer to the US model, with the Bologna Declaration. In the Gulf region, third-level education strives to produce educated nationals of equal standing to the West, and is seeking regional and international recognition through ABET accreditation [10]. However, cultural, linguistic, economical, social and political factors, can constrain the level to which Western education models can be implemented in the region [5].

Such factors add a further dimension to understanding and practising modern engineering for entry-level United Arab Emirates (UAE) students. As the local population does not have a long tradition of occupations in engineering, opportunities to interact with engineers can be more limited than elsewhere. Indigenous professionals are outnumbered by expatriates, who do not necessarily speak Arabic. Furthermore, the UAE's industry is strongly focused on key sectors, namely oil and gas, information technology (IT), civil and infrastructure manufacturing [11], with the result that the workforce does not have direct exposure to the full diversity of possible engineering career paths. Despite the opportunities that the local oil and gas sector will continue to offer for decades to come, it is important for the UAE's government and education system to prepare tomorrow's engineers for the development of other industries (e.g. alternative energy sources), which have the potential to further contribute to the region's wealth in the 21st century and beyond. Technology news on sources including *Newsweek, Time,* Sci*entific American* and *ASME* mechanical engineering magazine offer valuable insight into modern ME applications, in a style and format intended for the non-specialist. However, the fact that such information can only be accessed in a foreign language is an additional barrier to knowledge dissemination, although English is the primary language in third-level engineering education. Other challenges faced by the Gulf's engineering education include cultural, moral and learning issues [11, 12]. Gulf students exhibit characteristic strengths and weaknesses. The former include natural affinities for team-work and good oral presentation skills, while weaknesses can be found in reading large portions of authentic text, writing, expecting to be passive recipients of taught information and lacking independence in the approach to problem solving [11]. Instructors of natural science courses can struggle to complete course syllabi in the same amount of time as is allocated in Western universities, and feel that more time is required to cover key fundamental concepts, with no or insufficient time left to cover engineering technologies and applications, either in project assignments or dedicated lectures. Difficulties have been reported in meeting the goals of modern engineering education within a four-year curriculum, with major blocks of time devoted to building the background of students in areas not typical in Western engineering education [5]. Finally, retention issues are also encountered, which are attributable to the lack of financial incentives to work, and which can lead young nationals to opt out of professions that require high levels of preparation and dedication [13]. The above circumstances invite local universities to carefully consider adaptation of Western education models.

Established in 2001, the mission of The Petroleum Institute (PI) is to educate the local workforce in fields of engineering (Chemical, Electrical, Mechanical, Petroleum and Petroleum Geosciences) that will serve the on-going needs of the oil and gas industry in the Gulf region. The Institute, whose goal is to become a leading third level academic institution in the Gulf, has been working in cooperation with affiliate universities in the US and Europe, to tailor Western education models to the needs of the local industry. The five engineering curricula are taught in English, with the Foundation English Programme of the Institute being the first outside the US to be accredited by the CEA in 2006.

It is in the above context and in line with ABET outcomes that the two-credit sophomore course is presented below, Introduction to Modern Mechanical Engineering (MEEG205). It was felt that such a two-credit, discipline-specific course focusing on the modern and local ME profession and discipline, contributing to the development of attributes necessary for professional development [10,14,15]—including qualities expected in a design engineer [6]—would be a better solution to meet the programme's educational goals, in conjunction with the rest of the PI ME curriculum, than attempting to cover ME applications in fundamentals of engineering courses, as proposed by Larochelle *et al.* [4] in the US. Mainstream ME fields and practices are concisely covered, enabling emphasis to be placed on the petroleum industry and the broader energy sectors, as well as modern and emerging applications of ME. This strategy takes into consideration the employment sector of the PI students (oil and gas industry), UAE's long-term plans to develop alternative energy sources, and addresses the students' outdated perception of ME. The professional attributes targeted in MEEG205 consist of team, communication, ethical reasoning and societal and global contextual analysis skills, as well as motivation/initiative, curiosity and work strategies. The development of these attributes is addressed by the course's topical contents, structure and teaching methodology.

MEEG205 is carefully articulated with the remainder of the ME curriculum. To help the students make a more informed decision when selecting a major that will correspond to their skills and aspirations, MEEG205 is preceded by a one-credit, Freshman Success seminar (ENGR103), which provides an overview of the engineering specialisations taught at the Institute. The integration of design-and-build activities at an early stage in the PI ME curriculum is achieved through 'pre-capstone' design experiences (see, for example, Elata and Garaway [1], Nesbit *et al.* [2] and Larochelle *et al.* [4]), as part of a six-credit programme entitled Strategies for Team-based Engineering Problem Solving (STEPS 210 and 251). In this programme, the students integrate their knowledge in science, maths and communications, with team work and project management tools, to solve open-ended engineering design problems, including the design and construction of useful machines [16]. Professional attributes are also developed in the following common engineering courses, undertaken by all PI students. During the Freshman Success Seminar (ENGR103) previously mentioned, the students learn study skills and time management. Two 4-credit communication modules (COMM 101 and 151) prepare freshman students to follow a full curriculum in English, and provide them with a working knowledge of multi-media communication tools. During the STEPS design experiences, the students also practise a range of professional skills. Collectively, therefore, a significant number of credits, relative to Western educational practices, are devoted to building study skills and professional qualities. Although beyond the scope of this paper, the PI is currently driving an innovative high school project, which aims at an improved continuity [6] and articulation of engineering education with secondary school [5].

To the authors' knowledge, the present introduction to mechanical engineering (MEEG205) is unique in the Arabic Gulf region. Although three other universities in the region also offer engineering introductory courses, these are discipline non-specific. The main objectives of MEEG205 are to:

- raise entry-level students' understanding of the modern ME profession and discipline
- reinforce student motivation and curiosity to pursue their ME professional and educational goals
- prepare the students for the ME curriculum and real-life engineering practice in the local and global working environment
- familiarize students with engineering tools
- develop professional attributes, including team, communication and ethical reasoning skills, awareness of the economic, societal and global context for engineering solutions, to increase awareness of the importance of lifelong learning, to engage in self- and peer evaluation, to exercise initiative, curiosity, and to practice work strategies.

The course outcomes and their relationship to ABET criteria for accrediting engineering programs [10], denoted in brackets, are as follows to demonstrate:

- a general understanding of the modern ME discipline and profession, in terms of their evolution, curriculum, relationship to other disciplines, career paths, application areas including the oil and gas industry, contemporary issues and future directions (h, j)
- an awareness of the global, economic, environmental and societal context of an engineering problem (h)
- an ability to use techniques, skills, and engineering tools necessary for modern engineering practice (k)
- a competency in sourcing, evaluating and analyzing information related to a engineering topic (i, g, k)
- a competency in oral and written communication, in a simulated engineering related context (g)
- effective team work in a simulated engineering context (d)
- awareness of professional and ethical responsibility (f)
- an ability to acquire new knowledge independently (i).

COURSE TOPICS, STRUCTURE AND FORMAT

The topics, structure and format of MEEG205 were designed to address the above outcomes, in tandem with the rest of the PI ME curriculum. The course commences with an historical perspective of ME, reviews the ME curriculum and introduces applications of the fundamentals to different areas, with emphasis on the oil and gas industry. The course progresses to the use of engineering tools, focusing on codes and standards, computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), and sources of scientific information. Once the students are familiar with traditional fields of ME, significant blocks of time are devoted to exploring the directions of ME in the 21st century: biotechnology, micro/nanotechnology, energy/ecology and information technology [14].

The course is implemented in one semester, 19-week structure, with a two-hour meeting each week. The format of the lectures is oriented towards interactive learning, where the students become active participants and constructors of their own knowledge, rather than passive recipients of taught information [7, 11]. The instructor's notes and short presentations are essentially used as a support to catalyze student participation, and to subsequently refine or correct student understanding of a particular topic. Many opportunities are given for the students to engage in oral and written communication, team work, independent learning and critical thinking, characteristics that should be emphasized in young Gulf archetypal students particularly [11]. This is achieved through team-based activities involving sourcing, evaluation and analysis of technical information, leading to in-class debates/discussions and presentations varying from informal or spontaneous (e.g. commenting on information) to formal and well-prepared (using a data projector). These activities involve the use of technical publications, technology/business news, educational videos, internet-based animations, invited lectures by industry experts and alumni sharing their job experiences, and a field trip. Therefore, overall, the course format utilizes a student's natural oral communication skills to enhance effective learning, while also tackling potential weaknesses in written communication and passive and dependent learning practices that were possibly inherited from pre-tertiary education. The course is structured as follows:

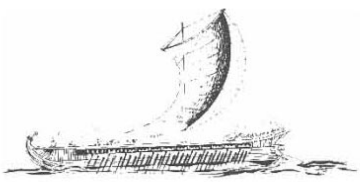
- Three in-class activities involving informal presentations, discussions or tutorials on topics such as history of ME, link between the ME curriculum and ME applications areas, ME career paths, analysis of codes and standards, professional ethics
- Three formal student presentations accompanied by in-class discussions on topics such as expert predictions of peak/plenty of oil availability scenarios, gas processing, renewable energy sources, a typical CAE analysis process and application, and the analysis of a major public-domain ethical case in engineering
- Eight application-area specific instructor presentations or invited lectures accompanied by class debates/discussions (e.g. ME design process, thermofluid applications in the oil and gas industry, product reliability, mechatronics, hybrid vehicles, prospects for a hydrogen economy, fuel cells, micro/nanotechnology, bioengineering)
- One educational video (e.g. ME in the electronics industry) accompanied by in-class discussion
- One computer-based library literacy laboratory
- One meeting with alumni sharing their job experiences
- One field trip to local industry
- Quizzes, homeworks, mid term and final exam.

For conciseness, only a snapshot of the course activities outlined above are presented in this paper, to illustrate the topical contents of the course and teaching methodology. This sample is limited to the following portions of the course:

- Historical perspective of ME
- Computer-based library laboratory on searching and evaluating scientific information
- Student presentation and in-class debate on predicted oil scenarios
- Field trip to a major gas processing plant in the UAE
- Invited lecture on fuel cells and prospects for a hydrogen orientated economy
- Engineering ethics, including the analysis of a public-domain case.

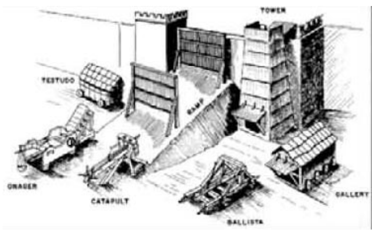
HISTORICAL PERSPECTIVE OF ME

In this activity, the class works in teams to build a historical perspective of mechanical systems and



a) Man-powered ship

b) *De Rebus Bellicis*, an ox-powered boat (~ 4 A.D.)



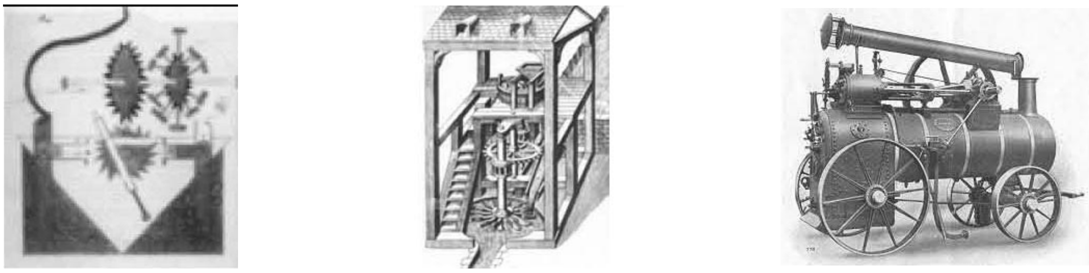
c) Greek, Macedonian and Roman military machines

d) Roman changing room having a finned-wall cavity heating system (200 B.C.–79 A.D.)

e) The Korean *Ondol* (37 B.C.–668 A.D.), a building heating system

f) The Antikythera Mechanism (~100 B.C.), a geared astronomical calculator

Fig. 1. Antique machines.



a) Islamic suction piston pump water-raising machine (1206 A.D.)

b) Water-driven grain mill (1600's A.D.)

c) Steam-driven tractor (1800's A.D.)

Fig. 2. Examples of water-and stream-driven machines.

a) Babbage's differential mechanical computer (1820's)

b) The Enigma (1920's onwards), a portable battery-powered cipher machine to electrically encrypt and decrypt secret messages. The mechanical parts form a varying electrical circuit.

Fig. 3. Machines illustrating the transition from mechanical (a) to electro-mechanical (b) systems.

a) Mars rover (2004), illustrating mechatronics

b) Pill camera (2001+). The latest prototypes contain a lens, a video chip and lamp, a microactuator, a power and data antenna, and a microfluidics-based lab-on-chip.

Fig. 4. Mechatronics and biomechatronics applications.

the ME discipline. The objective is for the students to gain an appreciation of the past contribution of ME and technology to society, and how mechanical systems have evolved. This perspective gives the students a view of the contribution they could make by being creative, and thus a sense that they can influence the future. Historical aspects can constitute a new concept to certain students, as history is not systematically included in first and secondary level education in the UAE. In this regard, the PI curriculum also includes two three-credit social science electives, titled *The UAE Before and Since Oil* (H&SS 222) and *The West in the Middle East* (H&SS 201).

Before the class, the students work in teams to identify mechanical systems designed at different periods, spanning antiquity, the middle ages or renaissance, industrial revolution, early and late 20th century, and 21st century. Examples of systems spanning these periods are illustrated in Figures 1 to 4. The students justify their system selection and identify the mechanical engineering effort that would be involved today in the design of such machines. Each team presents their findings during the class. The students evaluate each others findings and presentations by completing a questionnaire and making constructive comments orally. The evaluation includes identifying key elements of technological progress in each mechanical system. For example, the machines shown in Figures 1 to 4 illustrate the evolution of power generation, from man- and animal-powered, to water-, steam-, and electricity-driven machines.

The modernism of both the Roman communal room heating system (Figure 1d) and the Korean Ondol (Figure 1e) resides in the concept of heat integration/utilization, which is a major research area in ME today. The degree of complexity and miniaturization of the Antikythera Mechanism (Figure 1f), a geared astronomical calculator, is also remarkable. While these examples are pre-islamic, relating teaching material to historical and cultural Arabic/Islamic heritage, can be a useful motivator for Gulf regional students [17]. Two prominent scientists of the Arab world contributed a number of advances in mechanical engineering. Ibn al-Haytham (965–c. 1039) formulated the concepts of inertia, momentum, and frictional force [18]. His pioneering of the scientific method in the use of experiments to verify theoretical hypotheses is considered one the most important scientific developments of the second millennium [19]. Al-Jazari (1136–1206) authored the Book of Knowledge of Ingenious Mechanical Devices (*Kitáb fí ma'rifat al-hiyal al-handasiyya*) [20] in which he described fifty mechanical inventions. These include the crankshaft, connecting rod, water-raising machines such as the watermill, suction pipes/pumps (Figure 2a), and the earliest water supply system driven by gears and hydropower, which was built in 13th century Damascus. Ibn al-Haytham's and Al-Jazari's inventions highlight Islamic contributions to present day mechanical engineering.

The students' attention is then drawn to the expansion of ME applications, most of which were limited to military, civil and agricultural uses before the industrial revolution, to a number of application areas in the 20th century. The evolution of computer technology (Figure 3a) illustrates the transition from purely mechanical to electro-mechanical systems, as well as progress in miniaturization and functionality. The 20th century's electro-mechanical systems are then contrasted with emerging bio-mechanical or bio-electro-mechanical systems of the 21th century, pointing to the future directions of ME. The examples in Figures 1 to 4 highlight increased cross-discipline interaction, which culminates with biomechatronics (Figure 4b).

To sketch the evolution of the ME discipline, in terms of the subjects taught, the students are invited to name scientists who contributed to ME fundamentals. As many students in the class have attended or are attending in parallel statics, dynamics and thermodynamics courses, they are familiar with scientists of the 17th to 19th century who developed mechanics (e.g. Newton, Hamilton, Lagrange) and thermodynamics (e.g. Boyle, Kelvin). The need for universities to develop ME as a separate field in the early 19th century, to provide manufacturing machines and the engines to power them, is highlighted. Based on this discussion, the evolution of the discipline is depicted from its classical origins, Mechanics and Thermodynamics [14] to a contemporary curriculum. To conclude, the students are invited to interpret and comment on ASME's educational council's vision of the discipline, as evolving from 'the branch of engineering that encompasses the generation and application of heat and mechanical power and the production, design and use of machines and tools', to 'one that addresses societal concerns through analysis, design, and manufacture of systems, at all size scales' [14].

CURRENT TECHNOLOGIES AND APPLICATION AREAS IN ME

In this section of the course, the students gain an insight to various fields within ME, with emphasis on the petroleum industry. An initial two-hour session is devoted to discussing the engineering profession, reviewing the PI ME curriculum and highlighting applications of the fundamentals to practical engineering activities. Rather than the instructor supplying the information, the class is divided into 'reflection groups' which summarize their combined knowledge of a particular topic by completing a detailed questionnaire. Examples of reflection topics include contrasting engineering and science, identifying engineering skills, describing the main engineering fields, illustrating concurrent engineering, contrasting mechanical engineering specializations (e.g. mechanical versus petroleum engineering), career paths and working environments, identifying mechanical engineering products and activities in a given industry sector, comparing the tools available to the 21st century engineer versus those available a few decades ago, identifying growing application areas in mechanical engineering, and the role of ASME and scope of its activities. Each group presents its thoughts to the rest of the class, and a global discussion is engaged in to refine the results. In this activity, the instructor tends to act as a moderator, the objectives being to encourage active involvement by students through a lively discussion and independent learning, to develop student confidence to present students' views to their peers, to make constructive comments on their peers' work and, conversely, to accept and benefit from criticism. The instructor circulates and monitors the teams, and provides hints and feedback. Application areas of ME are discussed in more detail in subsequent lectures. Two topical activities are presented below: the petroleum industry and ME in electronics.

ME applications related to the petroleum industry

To provide the students with economical, societal and technological context associated with the planet's energy challenges, a two-week course work is organized on the peak oil / plenty of oil debate [21]. In teams, the students source information on oil scenarios using the Institute's library facilities, internet, databases of scientific information and, when required, by seeking clarification from Faculty members in the Petroleum Engineering and Geosciences Programmes. A library literacy laboratory is held under the supervision of a librarian and the instructor, during which the students learn to use databases such as INSPEC and COMPENDEX and other sources that document their project topic. In a subsequent lecture, each team presents its literature review and personal interpretation to the class, by highlighting in more detail a particular oil scenario or expert's perspective. This activity makes students sensitive to the context of their future employment sector—the local oil and gas industry—and highlights the contribution that they could make to help resolve the planet's energy challenges. This topic also prepares the students for a subsequent session on alternative energy sources.

Most students were found to be very receptive to the peak oil / plenty of oil controversy, which they closely related to, and they became emotional when sharing their views. The instructor helped the students refine their interpretations and moderated their views, for example, when these tended to be one-sided or based on matters of personal preference rather than scientific and balanced arguments.

Following on from this introductory activity to the energy industry, subsequent lectures are organized on thermofluid applications in the oil and gas industry (e.g. heat exchangers used in various oil and gas processing steps) and product reliability (e.g. reliability challenges in plants, pipelines and oil and gas electronics, reliability assessment methodologies). In addition, a meeting is organized with members of Alumni employed in the local oil and gas industry, who share their job experiences with the class.

ME and electronics

Electronics is an important topic for entry-level ME students, who must understand that the integration of electronics with mechanical systems is a backbone of the 20th century's ME achievements [22]. This highlights the need for interdisciplinary and cross-disciplinary skills. There are two facets in introducing the interaction between electronics and ME to the students: the role of electronics in today's mechanical systems, and conversely, the mechanical engineering effort involved in designing, manufacturing and sustaining electrical and electronic systems.

Regarding the first facet, the students are confronted with the fact that the performance and functionality of today's machines has been in large part enabled by electronics and progress in miniaturization. The instructor presents industry trends on semiconductor device miniaturization (e.g. Moore's law) and the evolution of computing capability. An educational video provides additional insight into the semiconductor industry and semiconductor manufacturing and encapsulation processes. As an illustrative example, the principles of photolithography, a key enabling technology for transistor scaling, are summarized. During a field trip to local industry, the students came to appreciate how electronics have enabled an increased level of automation in oil and gas recovery equipment.

Many MEs employed in the local oil and gas fields specialize in failure analysis of oil and gas production and transportation equipment. A substantial portion of such failures can be caused by the electronics [23]. Therefore, it is important to stress to ME students that in designing and maintaining a mechanical system, basic cross-disciplinary skills in electronics may be required. A meeting was organized with a PI ME graduate who shared his job experiences of failure analyses of rotary equipment used in local gas plants with the class. Also, a UAE researcher gave an invited lecture on his Ph.D. research in the area of mechatronics, undertaken at a leading Japanese university.

Regarding the second facet, MEs are needed in the electronic industry, for designing, manufacturing to maintaining electronic hardware, from package level to cabinet and facility level. Most reliability analyses of electronic equipment and electronics cooling activities are undertaken by MEs. The students are familiarized with electronic cooling hardware such as fans and heat sinks. This part of the course is illustrated using practical case studies from industry, drawn from the instructors' industry experience [24].

The topic of electronics naturally leads to micro- and nanotechnology. For example, the relationship between device miniaturization, computing capability and mechanical sensing and actuation capability will be highlighted in microelectromechanical structures (MEMS).

EMERGING TECHNOLOGIES IN ME

Once students are familiar with mainstream ME fields and career paths, emerging directions of ME in the 21st Century are introduced. These directions identified as the four 'O's in ASME's educational council vision of how engineering education needs to adapt to address the needs of the twenty-first century's society and technology: Micr**o/**Nan**o** Technology, Inf**o**rmation Technology, Ec**o**logy/Energy and Bi**o**technology [14]. As illustrative examples, the Ecology/Energy and Micro/Nano Technology themes are summarized below.

Ecology/energy

Creating the 'energy engineer of 2030' is the long-term educational goal in the Gulf region [12]. In MEEG205, the ecology/energy theme is addressed though project work, an invited lecture and supporting information provided by the instructor. As a starting point, a sample of ME contributions to the energy and environment sectors are reviewed. This includes drilling techniques and equipment for improved oil recovery, energy-efficient cars, power plants, heat exchangers and HVAC systems, and the development of renewable energy sources.

In project work, the students research alternative energy sources, including solar, wind, biomass and nuclear energy, and summarize their potential advantages over hydrocarbon fuels. The students present their results in class and are invited to consider the potential and feasibility of implementing such alternative energies in their country. The instructor uses internet-based visualizations to clarify basic principles of fuel cell operation. The students search examples of fuel cell applications (e.g. power plants, portable electronics, fuel cell powered vehicles) from technology news such as the July 2006 issue of *Mechanical Engineering* [25, 26], which describes 'the car of the future', in which internal gasoline combustion engines are used in tandem or replaced with gas engines, hydrogen combustion engines or electric-powered engines. From their reading activity, the students are prompted to identify and summarize the concepts of hybrid cars and fuel cell-powered vehicles.

A recorded conference presentation by an international expert, Professor Peter Edwards from Oxford University [27], is also given on the prospects of a hydrogen-orientated economy and fuel cells as a way to utilize hydrogen as a fuel. Topics such as hydrogen production and storage, and carbon sequestration are introduced in this lecture. The instructor interrupts the presentation every few overheads and prompts the students to answer key questions that verify their understanding. The instructor highlights the professionalism required for conference presentations, draws attention to the structure and format of the presentation, sources of information employed, and other characteristics of the lecture as a model.

Other energy-related topics introduced in the course include microbial enhanced oil recovery (MEOR) and environmental engineering, as part of a separate session on bioengineering.

Micro/nanotechnology

ME has evolved as a discipline capable of analyzing, designing and manufacturing components and systems at all size scales [14], prompting the need for multi-scale engineering education [28, 29]. Electronics and electronic packaging are a good example to illustrate the scaling of engineering applications; students were introduced to Moore's law and its impact on computing capability in an earlier lecture. As a follow up, an introduction to MEMS and their fabrication is given. MEMS are an extension of integrated circuits that contain micro-scale sensors and actuators, such as gears and pistons, features that were only designed at macro-scale in the past. After the lecture, the students are invited to find additional MEMS applications (e.g. automotive airbag accelerometers, digital micro arrays), identify the functionalities of the sensing and actuating parts and highlight the multi-physics nature of the MEMS operation when applicable.

From micro-scale, the course progresses to nano-scale. Students are introduced to the concepts, challenges of nanotechnology, its potential applications and perceived risks. Their attention is drawn to the September 2006 issue of *Mechanical Engineering* [30], which highlights, for example, carbon nanotubes (CNTs) and fullerenes, two types of engineered nanostructures which are now finding a multitude of applications—for example, in composite materials due to their outstanding mechanical properties. Other applicational areas covered include biomedical sensors, diagnostic and treatment devices including futuristic nano-robots and nano-scale particles for targeted drug delivery to treat cancers in a localized manner. The students are invited to consider the foreseeable advent of nano- and molecular computers.

ENGINEERING TOOLS AND PRACTICES

Three categories of engineering tools are emphasized in the course: codes and standards, CAD/CAE/CAM and sources of scientific information.

Students are prompted to reflect on the need for and origins of codes and standards. From the industrial revolution onwards, products were manufactured using machinery, requiring modularity so that parts manufactured in different factories could be assembled together. The formation of ASME was partly motivated by the need for standards for the design of pressure vessels, which in the 1880s failed catastrophically due to a combination of poor design, manufacturing and use conditions. The use of codes and standards is highlighted for various equipment, including consumer products. Students complete assignments to familiarize themselves with the various standard bodies (e.g. ASTM, BSI, IEEE, ISO), and the type of technical definitions and guidelines used by designers, manufacturers and operators in industry in order to comply with a given standard.

From the authors' observations, many students have a poor appreciation of the need to source technical information (e.g. perform a literature review) in the conceptual phase of a design activity, such as a Senior Design course. In addition, entry-level students possess basic internet search skills, but generally have difficulty in evaluating the credibility, relevance and usefulness of technical information. As previously mentioned, the information literacy skills of young students in the Gulf region can be impaired by difficulty in understanding large sections of authentic text [11]. In addition, entry-level students are unaware of databases of scientific publications such as INSPEC and COMPENDEX. To address these weaknesses, a computer-based lab is held at the library, where the students learn to use such databases and other sources to document a contemporary engineering topic such as oil production scenarios. This lab is scheduled at the commencement of the semester, so that students can practise the use of databases in other assignments in the current course and throughout the remainder of their curriculum. Students practise to quickly scan the fields of a publication (e.g. title, abstract, conclusions, section titles, graphics, author affiliation) and to assess its relevance, usefulness and credibility. At the completion of the lab, the students hand out the list of technical publications they have sourced, that they will use in project work (e.g. the peak oil/ plenty of oil project). The students are invited to critically compare the characteristics and contents of information they have sourced from the internet, scientific databases and textbooks.

Various computer tools and their applications are introduced: programming (e.g. Matlab), equation solvers (e.g. Mathematica) and sophisticated CAE programs used in industry (e.g. computational fluid dynamics, stress analysis software). The instructor explains how engineers use theoretical analysis to estimate behaviour, and CAE to make predictions and create designs. This is illustrated using a typical CAE simulation process for an analysis typical of ME. Of particular importance is understanding the limits of engineering theory and CAE model in predicting actual system performance. Both the capabilities and potential limitations of CAE are highlighted. Experimental and virtual prototyping are contrasted, and how they complement each other. Practical case studies are presented to illustrate the use of CAD/CAE/CAM, such as the design of a car, simulation of its performance (e.g., car aerodynamics and engine stress analysis) and car manufacturing. Students complete an assignment to find and compare characteristics of commercially-available CAE tools (e.g. in terms of their modelling capabilities and application areas) based on online product literature, and to summarize a typical example of an application of such tools to a given ME design or analysis activity.

ENGINEERING ETHICS

The purpose and contents of professional codes of conducts, including the ASME code of ethics, are explained and illustrated through a tutorial and the analysis of a major public-domain case (e.g. the Challenger and Columbia space shuttle disasters, the Ford Pinto gas tank, the Exxon Valdez oil spill). After analyzing the case, the students present their findings to the rest of the class. The tutorial focuses on ethical situations representative of a corporate environment (e.g. issues arising in dealings with colleagues, customers and third parties) and is based on material from the NCEES Fundamentals of Engineering examination.

Randeree [17] suggests that relating the teaching of ethics to religious duty, for example, through Islamic sayings, can improve student motivation. However, non-Muslim instructors should exercise caution not to misinterpret such sayings.

FIELD TRIP

A one-day field trip to local industry is organized per semester, such as to an oil drilling or gas processing plant. Such trips provide opportunities for students to observe the working environment, familiarize themselves with ME specializations and various aspects related to the plant operation through discussions with engineers. An assignment is associated with the field trip, such as giving a presentation on a typical natural gas processing step, related equipment and the role of mechanical engineers. Such trips are generally very well received by the students, who find their visit extremely informative in terms of the working environment of a UAE mechanical engineer in the oil and gas industry. However, arranging for the students to meet Emirati engineers during the field trip is essential, not from a language perspective, but to offer role models and help the students relate engineering with their socio-cultural heritage.

CONCLUDING REMARKS

For most students, MEEG205 represents their first exposure to current and emerging technologies and applications in mechanical engineering. Mature and curious students reacted positively to this new information. However, during the first course offering, many students were initially sceptical of the usefulness of various topics, which were not fundamentals-orientated. The fact that most of the course did not involve calculations, but acquiring a general understanding of mechanical engineering concepts, appeared to be disorientating. Some students confused certain course topics with social sciences rather than engineering. Most students appeared to view an engineer as one who makes calculations and signs contracts, without appreciating the importance of researching, evaluating and synthesizing information at the early (conceptual) stage of a technical design or analytical activity. Similarly, knowledge of the history of technology and societal context for engineering solutions appeared superfluous to many students. Such reactions may be partly attributable to less emphasis being placed on humanities and social sciences in the local pre-tertiary education compared to the West. Few students appeared to read technology news, despite the availability of technology-orientated magazines and internet. To address these points, the instructors frequently forwarded technology/business news articles from, for example, the BBC's website and ASME's mechanical engineering magazine to the class.

Students also had difficulties identifying how much they should learn and what they should deliver to obtain good grades on assignments.

They realized that the knowledge of a professional engineer in a particular field of ME, could vary from novice to specialist level, and that they had latitude to decide how much they wanted to learn. The fact that a particular area of ME did not seem to have well-defined boundaries, unlike topics in other fundamental courses which progress chapter by chapter, also appeared to be confusing. To ease these issues, the students were provided with a set of self-assessment questions for each topical area. In addition, homeworks and quizzes were assigned that focused on answering key questions related to the course material. Students were also puzzled by the existence of cross links between ME and other engineering fields, and appeared to be reluctant to 'make space' to learn from other disciplines. For example, they initially questioned the need for a session on electronics in mechanical systems. The instructors had to provide detailed justifications.

Most students did not take sufficient notes during the class. Because the course was two credits, certain students had the perception that it should not involve significant work relative to three-credit subjects.

When working in teams, students were overly co-operative in terms of helping other teams. The instructors gave different assignments to the teams when possible and incorporated originality in the marking scheme.

Although Gulf students are respectful and friendly with Faculty members, the fact that most third-level instructors and local engineers are temporary UAE residents may be an additional barrier to learning. Larger numbers of Emirati instructors are necessary to provide role models, convince and enhance student responsiveness to new concepts and learning challenges.

Previously reported learning issues in the Gulf region [11] are consistent with such observations. Nevertheless, the instructors observed a continued improvement in student responsiveness to the course over a three-semester period. This is attributed to addressing learning needs and issues noted in previous semesters, in terms of course contents and delivery methodologies. This effort will be pursued in forthcoming semesters to further refine the course learning outcomes.

In summary, it was found that introducing ME to Gulf students requires tailoring to adapt to the local engineering job market, student learning characteristics, motivation and heritage. Unlike in modern Western introductory courses to engineering, pre-capstone design experiences are addressed in separate modules of the ME curriculum. This permits course topics to focus on the ME profession and discipline, including current and future applications, engineering tools and practices, ethics and the development of professional engineering attributes. The course topics required to be carefully justified and articulated to the students. Their delivery required both more time than in the West, and more active in-class student involvement through oral communication. For the students to open up to new educational models and learning practices, it was found that practical motivation methods, such as are suggested in this paper, can be critical. The motivation of regional Gulf students is addressed in more detail by, for example, Randeree [17].

Finally, the role of women is identified as one of four areas in the Arab world where 'change is taking place', where engineering educators could succeed [13]. Whereas in the US, for example, only 13% of ME students are women [31], the enrollment statistics of women in engineering in certain Arab countries are extremely encouraging [13]. However, female ME career paths are likely to differ from male ones due to cultural factors. Therefore, an introductory engineering course such as the present one, may need to be further tailored to the needs of female students, who will join the Institute's ME Program in Spring 2009.

REFERENCES

1. D. Elata and I. Garaway, A creative introduction to mechanical engineering. *Int. J. Eng. Educ.* **18**(5), 2002, pp. 566–575.
2. S. V. Nesbit, S. R. Hummel, P. R. Piergiovanni and J. P. Schaffer, A design and assessment-based introductory engineering course. *Int. J. Eng. Educ.* **21**(3), 2005, pp. 434–445.
3. A. Bar-Cohen. Mechanical engineering—the ever-evolving profession. Mechanical Engineering On-line, August, Available at http://www.memagazine.org/contents/current/webonly/wex81005.html (2005).
4. P. M. Larochelle, J. J. Engblom and H. Gutierrez, An innovative introduction to mechanical engineering: a cornerstone design experience. 2003 ASME Curriculum Innovation Award Honorable Mention. Available at http://files.asme.org/asmeorg/Governance/Honors/1108.pdf (2003).
5. R. C. Jones and B. S. Oberst, Foreign adaptation of US engineering education models. Available at http://www.worldexpertise.com (2001).
6. M. Welch. Learning to design: the continuum of engineering education. *Int. J. Eng. Educ.*, **23**(1), 2007, pp. 84–94.
7. R. Kimbell and D. Perry, *Design and technology in the knowledge economy*. Engineering Council, London (2001).
8. B. I. Hyman, From capstone to cornerstone: a new paradigm for design education. *Int. J. Eng. Educ.*, **17**(4), 2001, 416–420.
9. F. Bullen and D. Knight, The broad and strategic value of the freshmen engineering experience—FEE. *Int. J. Eng. Educ*,. **22**(6), 2006, 1241–1251.

10. ABET, Criteria for accrediting engineering programs—effective for evaluations during the 2007–2008 accreditation cycle. ABET, Inc., 111 Market Place, Suite 1050, Baltimore, MD 21202, USA (2007).
11. K. Randeree, Challenges in engineering education in the United Arab Emirates. *Learning and Teaching in Higher Education: Gulf Perspectives*, **3**(2), 2006.
12. M. M. Ohadi, Educating the energy engineer of 2030. Proc. First International Energy 2030 Conference, Eveloy, V., Rodgers, P., Al Hashimi, S., Ohadi, M.M. and Gupta, A.K. (Eds), November 1–2, 2006, Abu Dhabi, U.A.E, (2006). pp. 32–34.
13. R. C. Jones and B. S. Oberst, Quality engineering education for the Arab states region. Available at http://www.worldexpertise.com (2006).
14. W. Laity, W. Aung, R. Benson, J. Bernard, K. Fisher, F. Gourley, B. King, A. Menon, B. Nott, T. Perry, B. Simoneau, C. Stong, B. Warrington, and B. Wepfer, A vision of the future of mechanical engineering education. ASME council on education, November 2004, Available at http://files.asme.org/asmeorg/Education/College/ME/7782.pdf (2004).
15. US National Association of Colleges and Employers, Job Outlook 2007, student version. Available at http://www.naceweb.org (2007).
16. S. Scott and J. Ahmad, Preparing engineering students for environmental stewardship in the 21st Century: PI design teams develop plastics recycling plan. Proc. Third Annual Conference for Middle East Teachers of Science, Mathematics and Computing (METSMAC 2007), (2007). pp. 231–241.
17. M.H. Randeree, Influences of globalisation and culture on motivation of students in higher education in the UAE, *Gulf Perspectives*, **5**(2). 2008. Available at http://www.zu.ac.ae/lthe/lthe05_02_03_randeree.htm
18. Encyclopædia Britannica, Ibn al-Haytham, Available at http://www.britannica.com/EBchecked/topic/738111/Ibn-al-Haytham (2008).
19. B. Steffens, Ibn al-Haytham: *First Scientist*, Morgan Reynolds Publishing, ISBN 1599350246 (2006).
20. P. Hill, Al-Jazarí: *The Book of Knowledge of Ingenious Mechanical Devices*: Kitáb fí ma'rifat al-hiyal al-handasiyya, Springer (1973).
21. V. Eveloy, P. Rodgers, S. Al Hashimi, M. M. Ohadi, and A.K. Gupta (Eds), Proc. First International Energy 2030 Conference, November 1–2, 2006, Abu Dhabi, U.A.E (2006).
22. ASME, 20th Century Mechanical Engineering Achievements. Available at http://www.asme.org/Communities/History/Resources/20th_Century_Achievements.cfm (2007).
23. S. Tiku, A. F. Veneruso1, R. K. Etchells and M. Pecht, Risk factors in oil and gas well electronics compared to other electronic industries. Oil & Gas Science and Technology—Rev. IFP, 60(4), (2005). pp. 721–730.
24. P. Rodgers, V. Eveloy, and M. Pecht, Extending the limits of air-cooling in microelectronic equipment. Proc. Sixth International Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro-Systems (EuroSimE), (2005). pp. 695–702.
25. H. Hutchinson, Easy on the gas. *Mech. Eng*. **128**(7), 2006, pp. 26–34.
26. J. Winters, Juiced up. *Mech. Eng*. **128**(7), 2006, pp. 34–37.
27. P. P. Edwards, Hydrogen and fuel cells: a vision of our energy future. Proc. First International Energy 2030 Conference, Eveloy, V., Rodgers, P., Al Hashimi, S., Ohadi, M.M., and Gupta, A.K. (Eds), November 1-2, 2006, Abu Dhabi, U.A.E, (2006). pp. 38–40.
28. L. Lin, Curriculum development in microelectromechanical systems in mechanical engineering. *IEEE Transact. Educ.*, **44**(1), 2001, pp. 61–66.
29. G. Karami and R. Pieri, From continuum-based to multiscale-based engineering mechanics education. *Int. J. Eng. Educ.*, **23**(3), 2007, pp. 582–590.
30. J. Winters, No small risk. *Mech. Eng*. **128**(9), 2006, pp. 30–33.
31. B. Wolcott, Filling the void. *Mech. Eng*. **129**(2), 2007, pp. 24–27.

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