AC 2009-1182: COMPARISON OF INTERNATIONAL LEARNING OUTCOMES AND DEVELOPMENT OF ENGINEERING CURRICULA

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Comparison of International Learning Outcomes and Development of Engineering Curricula

Abstract

Various national and regional engineering accreditation bodies have developed sets of learning or program outcomes that serve as the foundation for the evaluation of curriculum quality. Some of the outcome structures are very broadly defined, leaving the details of curriculum design and the justification to the university and the accreditation evaluators. Other accreditation bodies define outcomes more thoroughly in topic and depth, with accreditation hinging on the general fit of the curriculum to these specifications.

Most of these outcome structures have been developed and used as accreditation standards predominantly over the last decade. During this time, existing curricula are usually altered and upgraded (that is, ‘retrofitted’) to meet the outcomes requirements. However, new degree programs and new engineering colleges have the opportunity to use the relevant outcomes as design specifications. Such a design ensures quality, prepares the college for future accreditation evaluation, and can be tailored to meet the needs of students and prospective employers.

This paper compares the outcomes structure and contents of several accreditation bodies, including the Engineering Council of the UK (EC^{UK}), EUR-ACE of the EU, and ABET of the USA. Similarities and differences between the outcomes of the bodies will be highlighted. The use of these accrediting standards as the basis of design specifications for engineering degrees at the Alfaisal University in Riyadh, Saudi Arabia will be presented. The designs for integrated BS, MS and PhD curricula were developed over a two-year period, based on the defined learning outcomes, by a committee comprised of the Founding Dean of Engineering and faculty from the Massachusetts Institute of Technology (MIT), the University of Cambridge and independent reviewers. Example BS and MS curricula and their fit to the outcome specifications are described.

Learning Outcomes

The development of learning outcomes by accrediting and professional education organizations has taken shape and been refined during the last decade for several reasons. Primary drivers are the recognition and adoption of the continuous improvement movement in higher education and the intent of accreditation organizations to place the burden of proof for education quality on the university. The latter aspect has led to the replacement of detailed degree program content imperatives with learning (or program) outcomes that allow the university faculty to develop and demonstrate how to best educate their students. The progression of learning outcomes development by accrediting agencies is evidenced by the publication and use of expected outcomes by organizations such as the Engineering Council of the United Kingdom (EC^{UK})[8], the European Federation of National Engineering Associations (EUR-ACE) of the European Union[10], and ABET, Inc. of the United States[1, 2].

In keeping with and advancing the spirit of learning outcomes is the more recent development of the CDIO (Conceive-Design-Implement-Operate) approach, pioneered at four American and European universities[7]. It is currently being implemented at various institutions around the world. While outcomes are commonly utilized to evaluate the quality of a degree program, the CDIO approach is best applied in the design, development and implementation of new or upgraded curricula. As stated in Crawley[7] (page 13), it applies the fundamental principle of engineering education that "… every graduating engineer should be able to: Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment."

Some published outcomes are very broadly defined, as illustrated by the ABET approach, with its Criterion 3 – Program Outcomes[1]. These well known outcomes (a)–(k), presented in Table 1, may be augmented or replaced by the program seeking US accreditation. However, the basic intent of the ABET outcomes must be demonstrated and used for ongoing program assessment by the faculty and administration.

Table 1. ABET Criterion 3 - Program Outcomes

Engineering programs must demonstrate that their students attain the following outcomes:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

For ABET accreditation evaluation, program outcomes are these plus any additional outcomes articulated by the program.

Other accreditation bodies have defined outcomes more thoroughly and numerously in topic and depth, with accreditation hinging on the general fit of the curriculum to the identified areas of understanding, knowledge, and skills. An excellent example is the Output Standards published by the EC^{UK} for the accreditation of Bachelor's and Master's programs[8]. The UK outcomes are categorized as general and specific. General outcomes, which identify a graduate's qualifications irrespective of the discipline, are categorized into four areas, as shown in Table 2. The specific outcomes, categorized into five areas, are developed and honed for a disciplinary program by the faculty and administration. The general and specific learning outcomes are given in Table 2 with characteristic examples of their content. (The letter codes in () are used to cross-reference with outcomes discussed in later sections.)

Table 2. EC^{UK} Learning Outcomes

General Learning Outcomes

- Knowledge and Understanding (KU) – appreciate the wider multidisciplinary engineering context; appreciate the social, environmental, ethical, economic, and commercial considerations of engineering decisions.
- Intellectual Abilities (IA) – apply quantitative science and engineering tools to problem analysis; demonstrate creative and innovative ability in problem solution and design formulation.
- Practical Skills (PS) – possess practical skills acquired through several means, including: laboratory and workshops exercises, supervised work in industry, individual and group project work, design work, and development and use of computer software.
- General Transferable Skills (GT) – demonstrate skill in problem solving, communication, team work, IT facilities and information retrieval; indicate self-learning and performance improvement skills as a foundation for lifelong learning.

Specific Learning Outcomes

- Underpinning Science and Mathematics and Associated Disciplines (US): 3 outcomes – know and understand principles, theories and methodologies pertinent to the discipline and their integration with associated disciplines.
- Engineering Analysis (EA): 4 outcomes – identify, classify, and describe systems and component performance via analytical methods and modeling techniques.
- Engineering Design (ED): 6 outcomes – identify and use constraints, user needs, cost drivers; manage design process and evaluate its outcomes.
- Economic, Social and Environmental Context (ES): 5 outcomes – understand and consider aspects such as sustainable development, legal requirements, ethical context.
- Engineering practice (EP): 8 outcomes – know and use relevant equipment, materials, processes and literature; consider uncertainty; be aware of quality, code and intellectual property issues.

Learning outcomes developed by the EUR-ACE emphasize quality and harmony between universities throughout the EU and with the UK system of outcomes and accreditation. The result is outcomes similar to those of the EC^{UK}, but defined more generally in terms of degree level and in terms compatible with the European Qualifications Framework (EQF)[9] for education and life long learning. This newly-developed reference framework relates different countries' qualifications within all of the European Union. Basically, EQF is a translation device that helps employers, individuals, governments and institutions better understand the education qualifications across the EU.

EUR-ACE learning outcomes are not categorized as general and specific, although the content is approximately the same as for the UK system (see analysis below). Rather, the EU uses the classification of First Cycle, which corresponds to the Bachelors degree (level 6 in EQF terminology) and Second Cycle, which corresponds to the Masters degree (level 7 in EQF).

When the wording, content and intent of the EC^{UK}, EUR-ACE and ABET outcomes are considered, we draw these qualitative conclusions:

- The EU outcomes[10] are written using somewhat less detailed terms than those of the UK[8], and
- The ABET program outcomes (Table 1) use very broad terms compared to UK and EU learning outcomes for higher education.

Regardless of the differences in structure and wording, it can be concluded that all three sets of outcomes provide similar quality bases for accreditation.

These US, UK and EU outcomes serve as the basis for the design and development of bachelors, masters and doctoral engineering curricula to be offered at an emerging university in the Kingdom of Saudi Arabia. After the university environment is described, these three systems and the resulting integrated outcomes employed for curriculum design and development at this new institution are compared and analyzed.

Alfaisal College of Engineering Environment

Alfaisal University is an independent, private, non-profit, research-intensive university of science and technology located in Riyadh. Founded by the King Faisal Foundation, the University's degree programs in Engineering, Science, Medicine and Business are designed to have an international outlook and are intended to be competitive with the highest quality institutions worldwide. Engineering degrees at BS, MEng, MS, and Ph.D. will be offered, with Bachelors degrees initiated first. Additional details are available in an earlier article[5] and on the university's website (www.coe.alfaisal.edu)[4].

A multi-national collaboration resulted in the design of the engineering academic programs and curricula. The Dean of Alfaisal Engineering, six engineering faculty of the Massachusetts Institute of Technology (MIT) in the US and six faculty of the University of Cambridge in the UK, all of whom serve as independent consultants, form the Alfaisal Engineering Program Committee (AEPC). After developing the learning outcomes based on accreditation standards, the AEPC has been deliberating for a period of over two years on the design of curriculum and course contents for each degree. Design input was also received from several of the members of the Alfaisal Board of Trustees, representing leading employers of engineering graduates and Saudi government agencies.

Learning Outcomes Comparison

The Committee reviewed the learning outcomes utilized in EC^{UK}, EUR-ACE, and ABET environments, and formulated a comprehensive outcomes package for all degree levels (referred to as the AEPC learning outcomes). The Appendix includes the AEPC outcomes for the undergraduate program. Outcomes are organized similar to the EC^{UK} and EUR-ACE outcomes in that they are grouped into four general and five specific outcome groups utilizing a structure similar to that of Table 2.

Table 3 provides a comparison of the content of the four outcomes structures for an undergraduate degree. The AEPC and EC^{UK} outcomes are similarly grouped, and the AEPC outcomes are written in a style and wording compatible with that of the UK and EU. Specific and general outcomes are used for AEPC and UK. There are additional outcomes for AEPC because the CDIO syllabus, mentioned earlier, was also utilized as a verification tool to ensure more complete coverage in areas that may be vague or missing in the European and American versions. The eleven ABET outcomes have generally similar coverage as other structures, although they are not clustered and the wording defines much broader areas for accreditation evaluation. Often it is difficult to identify one ABET outcome that corresponds to a single outcome in the other systems; thus the reference to two or more corresponding ABET outcomes. Incorporation of CDIO into the AEPC outcomes could not be readily implemented in chemical engineering and materials science and engineering.

Table 3 also shows that the AEPC outcomes span the quality specifications of the EC^{UK}, EUR-ACE and ABET outcomes structures. A final conclusion by AEPC members was that utilization of the AEPC outcomes to design, develop and implement a bachelor's level curriculum will result in a quality level that warrants accreditation in any academic environment in the world. With this goal in mind, these outcomes were used as the primary design guide (specifications) for the structure, courses, course content and detailed syllabus of all courses in the bachelors degree programs. Similar results were reached for the graduate level degrees and outcomes.

Table 3. Comparison of Outcomes Contents

Outcomes Category	AEPC		EC^{UK}		EUR-ACE	ABET
	Specific	General	Specific	General	1st and 2nd cycle	
Underpinning Knowledge and Understanding	US1-5	KU1-8	3 outcomes; same coverage as AEPC	Less coverage than AEPC	Same coverage as AEPC & EC^{UK} specific; less than AEPC general	a, h
Engineering Analysis	EA1-4		4 outcomes; same as AEPC		Same coverage as AEPC & EC^{UK}	b, e, k
Engineering Design	ED1-7		6 outcomes; same as AEPC		Slightly less coverage than AEPC & EC^{UK}	c, j
Engineering Practice	EP1-9		8 outcomes; same as AEPC		Less coverage than AEPC & EC^{UK}	k
Intellectual Abilities		IA1-7		Less coverage than AEPC		b, j
Practical Skills		PS1-8		Less coverage than AEPC		d, h
Investigations					Coverage includes parts of Practical Skills, Intellectual Abilities & Engr. Practice	b, c
Economic, Social, Environmental	ES1-7		5 outcomes; same as AEPC			f, h
Transferable Skills		GT1-7		Same coverage as AEPC	Same coverage as AEPC & EC^{UK}, plus majority of Economic, Social and Environmental	d, g, i, j

AEPC Curriculum Design

Application of the AEPC outcomes as the basis of the design was possible because of the unique opportunity offered by Alfaisal University to build the College of Engineering from scratch. While established schools with long-standing programs must consider transition issues in any major curricular revisions, the Alfaisal College of Engineering design was not so constrained. The considerations of the Committee, however, were driven by the need to create quality programs immediately recognizable in relation to those offered throughout the world and ones that will attract the best faculty available and, in due course, the best students.

The AEPC designs of the undergraduate and graduate structures benefit from the U.S., British, and European models of higher education. The structure of the undergraduate engineering curriculum is shown in Figure 1. The basis of all degrees is a common core of math/science/engineering foundation courses. The same set of courses is taken by all engineering students, regardless of their major. Discipline specific core courses build on this foundation, with advanced courses providing depth within the major. Each engineering degree includes a capstone course which provides an extended design and development exercise within the major. The degree requirements include humanities and social science courses to complete the degree program.

The utilization of a common design of math/science/engineering foundation courses and a specific number of common core and discipline-specific advanced courses has several advantages. It makes the degrees more compatible with each other and the AEPC outcomes, and it allows student transfers between degrees for a longer period of time than most international curricula. Further details of the curriculum design are given in the following section.

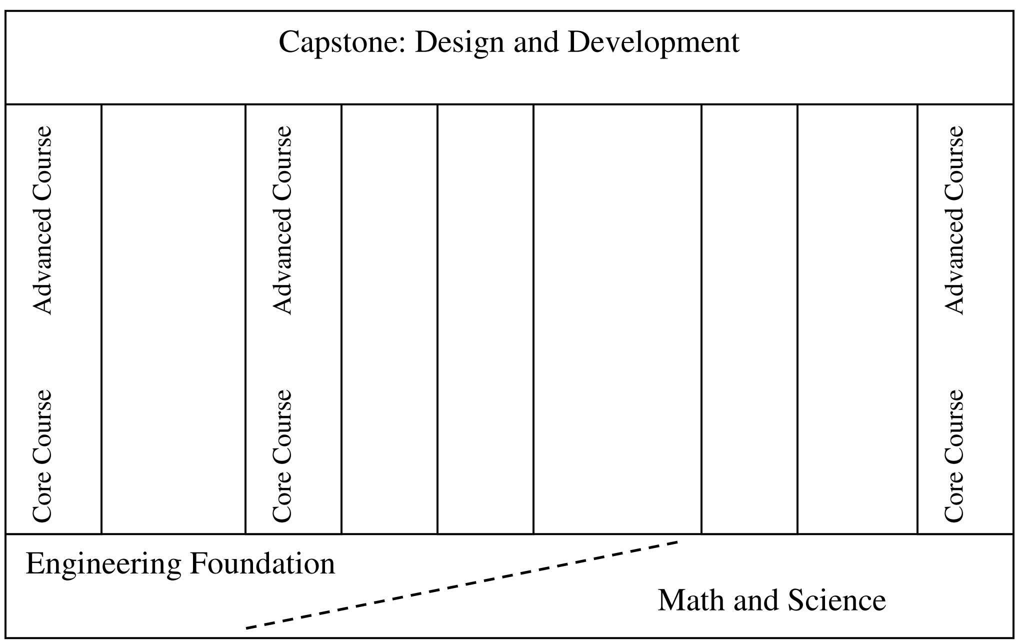

Figure 1. Graphic of Generic Undergraduate Engineering Curriculum

Undergraduate Curriculum Structure and Features

All undergraduate programs are designed along disciplinary lines with a thorough interdisciplinary foundation. The degree title includes the phrase 'Science and Engineering' to emphasize the scientific foundations of the field of study, applied science, and engineering. The BS degree programs are typically four years, 138 semester credit hours in duration and include a summer internship.

One important feature of the generic BS degree program (Table 4) is the teaching of foundation principles, theories, and applications of all the major engineering disciplines to each engineering student during the first two years. The five Foundations in Engineering courses are designed to:

- Provide multidisciplinary engineering education at a foundation level;
- Develop opportunities for team-based project activities;
- Expose students to the established analysis-synthesis and CDIO loops in engineering;
- Expose students to the fundamental tools and technologies of engineering disciplines;
- Enhance the interdisciplinary thought processes so important to professional engineering practice;
- Offer a fundamental preparation for graduate studies in most engineering disciplines.

The first year includes a significant project orientation designed to motivate students and to address the continuing issues of disassociation between theoretical framework and design aspects[6] (page 23) and of student retention in engineering[12] (page 3). The plan includes seven core undergraduate courses in a discipline during the second and third year, and the fourth year requires six advanced-level courses plus a capstone design project course.

The core courses, which cover the major knowledge bases in a specific discipline, represent the second level of courses within a field of study, and teach applied science and engineering analysis. The advanced courses include considerable depth of topics in the discipline without sacrificing breadth.

Table 4. Generic BS Degree Plan

Subject	Subject
Year 1 - Fall	**Year 3 - Fall**
Math A: Multivariate Calculus and Linear Algebra	Core 2
Physical Science A: Mechanics, Thermodynamics, Waves	Core 3
Software Development and Engineering	Core 4
Foundations of Eng A: Mechanical and Aerospace	Humanities and Social Science (Arabic Studies)
Year 1 – Spring	**Year 3 - Spring**
Math B: Differential Equations and Numerical Analysis	Core 5
Physical Science B: Optics, Electromagnetism, Geophysics	Core 6
Chemical Science	Core 7
Foundations of Eng B: Electrical and Computer	Humanities and Social Science (Islamic Studies)
Year 1 – Summer	**Year 3 - Summer**
Service Activity (optional)	Undergraduate research (optional)
Year 2 – Fall	**Year 4 - Fall**
Math C: Discrete Mathematics and Graphs	Advanced 1
Life & Biological Sciences	Advanced 2
Foundations of Eng C: Materials, Chemical and Biological	Advanced 3
Foundations of Eng D: Civil, Environment and Petroleum	Science, Technology, Society, Policy, Ethics
Year 2 – Spring	**Year 4 - Spring**
Math D: Probability, Random Vectors, Statistics	Advanced 4
Humanities and Social Science (Economics and Management)	Advanced 5
Foundations of Eng E: Industrial, Systems & Management	Advanced 6
Core 1	Capstone Project
Year 2 - Summer	**Year 4 - Summer**
Systems Eng and Internship (required)	Professional Licensing Course; Exams (optional)

Example BS Degree and Course Contributions to AEPC Outcomes

The seven core and six advanced Mechanical Science and Engineering courses developed using the AEPC outcomes and generic degree plan are listed in Table 5 for purposes of illustration. The knowledge base(s) addressed by each course are also shown in the table. The AEPC members considered the contribution to outcomes for each course in a degree plan. The results of this lengthy, but centrally important, exercise for several courses that are required of all students and selected Mechanical Engineering degree courses are summarized in Table 6.

Table 5. Core and Advanced Courses for Mechanical Science and Engineering

Subject	Knowledge Base
Year 2 - Spring	
Core 1: Mechanics and Materials I – Strength of Materials	Strength of materials and structures Materials
Year 3 – Fall	
Core 2: Mechanics and Materials II – Behavior of Materials	Materials
Core 3: Thermal Fluids Engineering I	Thermodynamics Fluid mechanics Heat transfer
Core 4: Kinematics and Dynamics	Dynamics
Year 3 - Spring	
Core 5: Machine Elements	Machines
Core 6: Thermal Fluids Engineering II	Thermodynamics Fluid mechanics Heat transfer
Core 7: Introduction to Design with Project	Design
Year 4 – Fall	
Advanced 1: Manufacturing	Manufacturing
Advanced 2: Experimental Projects and Instrumentation Lab	Measurement
Advanced 3: Vibration, System Response	Vibration
Year 4 - Spring	
Advanced 4: Mechatronics	Electromechanical systems Design Control
Advanced 5: Modeling & Automatic Control	Modeling Control
Advanced 6: Product Development	Product development

Table 6. Contributions to AEPC Outcomes for Selected Courses

	GENERAL LEARNING OUTCOMES				SPECIFIC LEARNING OUTCOMES				
Category	**KU**	**IA**	**PS**	**GT**	**US**	**EA**	**ED**	**ES**	**EP**
Category Topic	**Know-ledge & Under-stand**	**Intel Abil**	**Prac-tical Skills**	**Gen Skills**	**Science & Math**	**Engr Anal**	**Design**	**Economic, Social, Environ-mental**	**Engr Practice**
# outcomes	8	7	8	7	5	4	7	7	9
Math D: Probability and Statistics	1,2,3,5	1,3,4, 5,6,7	6,8	2,5	2,3,4,5	3	4		3,8
Life & Bio Science	1,2,3,4, 5,8	3,4,5, 7	1,2,6		1,2,3	1,2	1,2,4,5	1,3,4,5	2,3,4,6,7,8
Software Dev & Engr	2, 4, 6, 7, 8	2, 3, 5, 6, 7	1-8	1,2,3, 4,6	2, 3	1, 2, 4	1,2,3,4,5, 6,7	1,2,3,5,7	1,2,3,6,7, 8,9
Foundations A: Mech & Aero	1,2,3,4, 5,8	1-6	1,2,5	1,2,3, 5,6,7	1-3	1-4	2,4,6	12,3,5	1,2,3,6,7
Thermal Fluids Engineering I	1,3,5	4,6	2	2,5,7	1,2	1-4	1		1,3
Manufacturing	1,2,3,4, 6	2-7	1,2,3, 5,6	2,3,5, 7	1,2,3	1-4	1-6	1,2,3	1,2,3,6,7,8
Exp Projects Lab	1,3,4,5	2-7	1,2,3, 5,6	2-7	1,2,3	1-4	1,4		1,2,3,4,8

Masters Level AEPC Outcomes, Curriculum and Examples

Tried and tested learning outcomes are not nearly as available for graduate programs as they are for undergraduate programs. Professional and higher education quality-related organizations in the United Kingdom are good international sources: EC^{UK}[8], Quality Assurance Agency[13], and Institute of Engineering and Technology[11]. Using the same structure and categories as the BS level, graduate learning outcomes serve as the basis for the design and development of the masters of engineering (MEng) and masters of science (MSc) degrees[3]. The categories are:

<u>General learning outcomes for MEng courses</u>

- Intellectual abilities (IAme) – 3 outcomes
- Practical skills (PSme) - 5 outcomes
- General transferable skills (TSme) - 5 outcomes

<u>General learning outcomes for MSc courses</u>

- Intellectual abilities (IAms) – 4 outcomes
- Practical skills (PSms) - 3 outcomes
- General transferable skills (TSms) - 5 outcomes

<u>Specific learning outcomes for both MEng and MSc courses</u>

- Underpinning science and mathematics (Sm) – 5 outcomes
- Engineering analysis (Am) – 5 outcomes

- Engineering design (Dm) – 3 outcomes
- Economic, social, and environmental context (Cm) - 3 outcomes
- Engineering practice (Pm) - 4 outcomes

Note that the general outcomes for the two degree programs are slightly different, although the specific outcomes are shared. The integration of the two masters degrees with each other and the doctoral degree is shown schematically in Figure 2.

Table 7 shows the generic degree plans for the MEng and MSc. The MEng program is typically of one year duration after earning the BS degree. Emphasis is placed on several concentration areas (sub-disciplines of a discipline) with separate courses in four different, but allied, areas. This is followed by reading courses in two of these concentrations. The degree is conferred after this year of study, or its equivalent.

The second year of study for the MSc degree involves further focus on one specialty area. For example, if the MEng degree is earned with a study of intelligent systems, the MSc work may target a specialty area, such as machine vision or language and speech. The MSc includes four formal courses in the specialty area and the research focuses on this specialty. The MSc includes the development of a research proposal and completion of the qualifying exam for individuals proceeding to doctoral level studies.

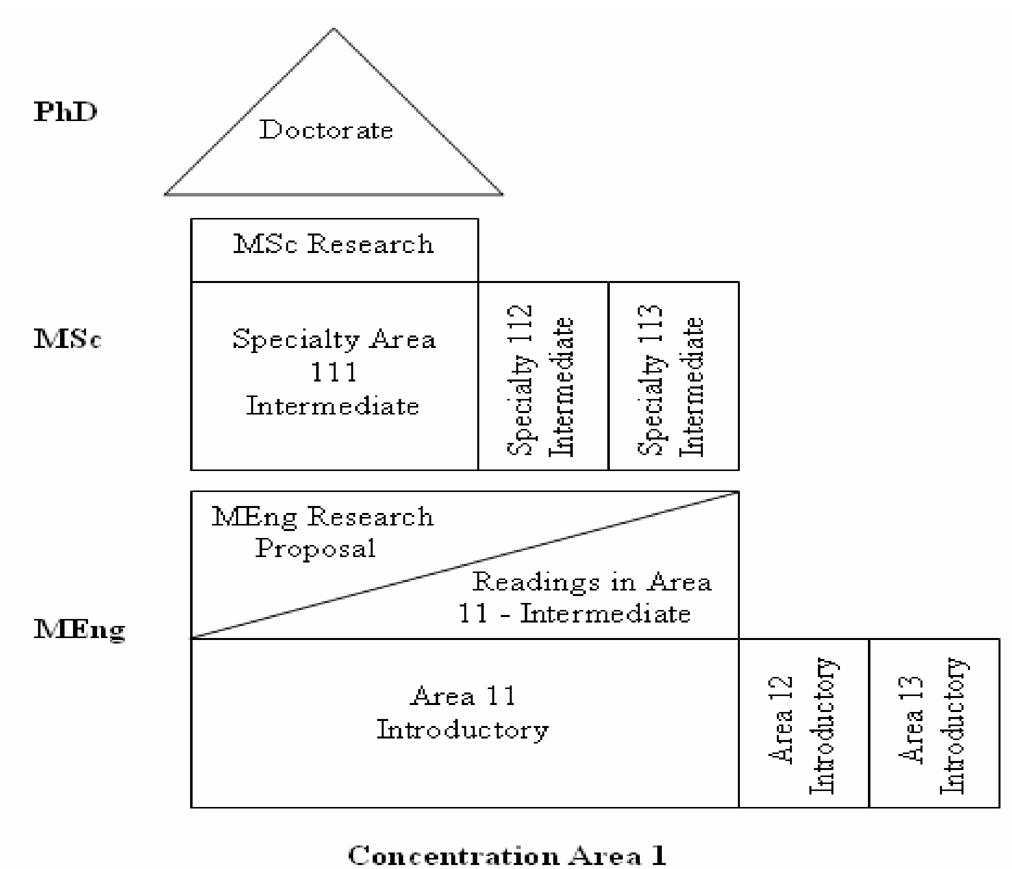

Figure 2. Graphic of MEng and MSc Curriculum Design

Table 7. Generic MEng and MSc Degree Plans

Subject	Subject
Year 1 - Fall – MEng	**Year 2 - Fall - MSc**
Strategic Management	Advanced 1: Subject in Area 1
Intro Graduate subject in Conc (Area 1)	Advanced 2: Subject in Area 1
Intro Graduate subject in Conc (Area 2)	Research Proposal I
Intro Graduate subject in Conc (Area 3)	**Year 2 - Spring - MSc**
Year 1 - Spring – MEng	Advanced 3: Subject in Area 1
Intro Graduate subject in Conc. (Area 4)	Advanced 4: Subject in Area 1
Intermediate Graduate Area 1 (Reading course)	Research Proposal II; Doctoral Qualifying
Intermediate Graduate Area 2 (Reading course)	
Research Project I	
Year 1 - Summer – MEng	
Research Project II	

A sample masters study curriculum is detailed in Table 8 with a selected MEng area of "applied mechanics". Four concentration area courses followed by reading courses in two of these areas are required. These are selected from the variety of concentration courses offered by the faculty. The MSc specialty area indicated is "dynamics, vibrations and control"; courses integrated with research in this area complete the 2 years of masters study.

Table 9 summarizes the contributions to outcomes for courses listed in the MEng example for applied mechanics. It is possible to analyze how thoroughly the entire masters work covers the expected outcomes by reviewing the relevant contributions of all MEng and MSc courses.

Again, published and established learning outcomes for doctoral studies are difficult to find. The AEPC doctoral outcomes are written in a general format using the categories:

- Knowledge
- Research skills and techniques
- Research environment
- Research management
- Personal effectiveness
- Communication skills
- Networking and team working
- Career management

Formal PhD-level courses, doctoral dissertation research, and two specially designed courses in teaching development, and research development and management contribute to these outcomes in varying and documentable forms.

Table 8. Example Graduate Level Concentration and Specialty Area Courses
MEng: Applied mechanics
MSc: Dynamics/vibrations/control

Subject
Year 1 – Fall - MEng
Area 1: Elasticity& Plasticity
Area 2: Vibrations
Area 3: Dynamic Systems & Control
Year 1 –Spring - MEng
Area 4: Num. Methods in Applied Mechanics
Reading 1: Vibrations
Reading 2: Dynamic Systems & Control
Year 2 – Fall – MSc
Advanced 1: Advanced Dynamics
Advanced 2: Nonlinear Vibrations and Chaos
Year 2 – Spring – MSc
Advanced 3: Impact and Wave Propagation
Advanced 4: Waveguide Acoustics

Table 9. Contributions to Outcomes for MEng Degree Courses

	MEng GENERAL OUTCOMES			MEng SPECIFIC OUTCOMES				
Category	**IAme**	**Psme**	**Tsme**	**Sm**	**Am**	**Dm**	**Cm**	**Pm**
Category Topic	**Intel Abilit y**	**Prac Skills**	**Gen Tran Skills**	**Sci & Math**	**Engr Anal**	**Design**	**Eco, Soc, Env**	**Engr Prac**
# outcomes	**3**	**5**	**5**	**5**	**5**	**3**	**3**	**4**
Strategic Mgmt	1,3	1,2,4	2	3,4			1,2,3	1,4
Elasticity& Plasticity	1,2,3	1,2	1-5	1,2,4,5	1-5	1,3		1
Vibrations	1,2,3	1,2	1-5	1,2,4,5	1-5	1,3		1
Dynamics Sys & Control	1,2,3	1,2	1-5	1,2,4,5	1-5	1,3		1
Numerical Methods	1,2,3	1,2	1-5	1,2,4,5	1-5	1,3		1
Readings in Vibrations	1,2,3	1-4	1,2,3	1,2,4,5	1-4	1,3	3	1,4
Readings in Dyn, Systems & Cont	1,2,3	1-4	1,2,3	1,2,4,5	1-4	1,3	3	1,4
Research Project I	1, 2	1, 2, 5	1-5	1-5	1-5	1-3	1-3	1,2,3
Research Project II	1, 2	1, 2, 5	2-5	1-5	1-5	1-3	1-3	1-4

Conclusion

A comprehensive set of learning outcomes has been developed to serve as the basis of the design of engineering curricula for undergraduate and graduate programs for the Alfaisal College of Engineering at Alfaisal University. The Alfaisal College of Engineering learning outcomes were drawn from previously defined and implemented outcomes for three international accreditation standards: EC^{UK}, ABET and EUR-ACE. A thorough comparison and analysis of these three systems of outcomes plus the AEPC outcomes indicates that high-quality, internationally recognizable curricula can be developed when using outcomes as the design specifications of the curriculum, courses and their contents.

This approach offers several advantages. First, the technique allows the design team to directly take advantage of work accomplished by the accrediting agencies in defining program quality. Second, employing internationally-proven quality standards in the design process improves the opportunities for future accreditation from these organizations. Finally, the approach will significantly enhance the success of graduates in work environments throughout the Middle East region, as well as in Europe and North America.

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Appendix

AEPC Undergraduate Learning Outcomes

General Outcomes

Categories:

- Knowledge and Understanding (KU)
- Intellectual Abilities (IA)
- Practical Skills (PS)
- General Transferable Skills (GT)

KU - Knowledge and Understanding

KU1: Knowledge and understanding of essential facts, concepts, principles and theories relating to the discipline and discipline-specific applications as appropriate to the program of study

KU2: Knowledge and understanding of the wider multidisciplinary engineering context and its underlying principles

KU3: Knowledge and understanding of the use of engineering principles, founded on appropriate scientific and technological disciplines

KU4: Knowledge and understanding of the use of scientific principles in the creation, use and support of systems based on the specific discipline for the solution of practical problems

KU5: Knowledge and understanding of mathematical principles necessary to underpin the program of study in the specific discipline and the ability to apply mathematical methods, tools and notations proficiently in the analysis and solution to problems

KU6: Knowledge and understanding of the commercial and economic context of the development, use and maintenance of systems based on the specific discipline

KU7: Knowledge of the management techniques which may be used to achieve objectives within a computing context

KU8: Recognize the legal, social, ethical and professional issues involved in the exploitation of technology in the specific discipline and be guided by the adoption of appropriate professional, ethical and legal practices

IA - Intellectual Abilities

IA1: Either the ability to use computational modeling for the purposes of comprehension of scientific phenomena or the ability to apply the scientific method in the solution of problems in the domain of the specific discipline

IA2: Demonstrate creative and innovative ability in the synthesis of solution and in formulating designs

IA3: Deploy appropriate theory, practices and tools for the specification, design, implementation and evaluation of systems based on the specific discipline

IA4: Recognize and analyze criteria and specifications appropriate to specific problems and plan strategies for their solution

IA5: The use of knowledge and understanding in the modeling and design of systems based on the specific discipline for the purposes of comprehension, communication, prediction and the understanding of trade-offs

IA6: Integration of the knowledge bases with the specific discipline

IA7: Analyze the extent to which a system based on the specific discipline meets the criteria defined for its current use and future development

PS - Practical Skills

PS1: Specify, design or construct systems based on the specific discipline

PS2: Evaluate systems in terms of general quality attributes and possible trade-offs presented within the given problem

PS3: Recognize any risks or safety aspects that may be involved in the operation of equipment of the specific discipline within a given context

PS4: Deploy effectively the tools used for the construction and documentation of applications in the specific disciplines, with particular emphasis on understanding the whole process involved in the effective deployment to solve practical problems

PS5: Operate equipment in the specific discipline effectively, taking into account its logical and physical properties

PS6: Use appropriate processes to specify, design, implement, verify and maintain systems based on the specific discipline, including working with technical uncertainty

PS7: Investigate and define a problem, identify constraints, understand customer and user needs, identify and manage cost drivers, ensure fitness for purpose and manage the design process and evaluate outcomes

PS8: Ability to analyze risk and communicate information for subsequent team decisions, communicate safety, environmental, ethical, or societal concerns affected by engineering decisions

GT - General Transferable Skills

GT1: An ability to work as a member of a development team recognizing the different roles within a team and different ways of organizing teams

GT2: Ability in problem solving

GT3: Work with others

GT4: Effective information management and information retrieval skills

GT5: Numeracy in both understanding and presenting cases involving a quantitative dimension

GT6: Communication skills in electronic as well as written and oral form to a range of audiences
GT7: Planning self-learning and improving performance as the foundation for on-going professional development

Specific Outcomes

Categories:

- Underpinning Science and mathematics (US)
- Engineering analysis (EA)
- Engineering Design (ED)
- Economic, social, and environmental context (ES)
- Engineering practice (EP)

US - Underpinning Science and Mathematics and Associated Disciplines

US1: Knowledge and understanding of scientific principles and methodology necessary to underpin their education in their engineering discipline, to enable appreciation of its scientific and engineering context and to support their understanding of future developments and technologies
US2: Knowledge and understanding of mathematical principles necessary to underpin their education in their engineering discipline and to enable them to apply mathematical methods, tools and notations proficiently in the analysis and solution of engineering problems
US3: Ability to apply and integrate knowledge and understanding of other engineering disciplines to support the study of their own engineering discipline
US4: Ability to collate, analyze and present mathematical and scientific results or concepts and communicate them effectively
US5: Ability to comprehend and develop knowledge in mathematics and science topics independently

EA – Engineering Analysis

EA1: Understanding of engineering principles and the ability to apply them to analyse key engineering processes
EA2: Ability to identify, classify and describe the performance of systems and components through the use of analytical methods and modeling techniques
EA3: Ability to apply quantitative methods and computer software relevant to their engineering discipline, to solve engineering problems
EA4: Understanding of and ability to apply a systems approach to engineering problems

ED – Engineering Design

ED1: Investigate and define a problem and identify constraints including environmental and sustainability limitations, health and safety and risk assessment issues
ED2: Understand customer and user needs and the importance of considerations such as aesthetics
ED3: Identify and manage cost drivers
ED4: Use creativity to establish innovative solutions

ED5: Ensure fitness for purpose for all aspects of the problem including production, operation, maintenance and disposal
ED6: Manage the design process and evaluate outcomes
ED7: Conduct bench-top, proof of concept experiments

ES – Economic, Social and Environmental Context

ES1: Knowledge and understanding of commercial and economic context of engineering processes
ES2: Knowledge of management techniques which may be used to achieve engineering objectives within that context
ES3: Understanding of the requirement for engineering activities to promote sustainable development
ES4: Awareness of the framework of relevant legal requirements governing engineering activities, including personnel, health, safety, and risk (including environmental risk) issues
ES5: Understanding of the need for a high level of professional and ethical conduct in engineering
ES6: Identify the societal, enterprise, and technical context of system, the external interactions and behavioral impact
ES7: Recognize entrepreneurial opportunities that can be addressed by technology, recognize technologies that can create new products and systems, and address entrepreneurial finance and organization

EP – Engineering Practice

EP1: Knowledge of characteristics of particular equipment, processes or products
EP2: Workshop and laboratory skills
EP3: Understanding of contexts in which engineering knowledge can be applied (e.g. operations and management, technology, development, etc.)
EP4: Understanding use of technical literature and other information sources
EP5: Awareness of nature of intellectual property and contractual issues
EP6: Understanding of appropriate codes of practice and industry standards
EP7: Awareness of quality issues
EP8: Ability to work with technical uncertainty
EP9: Ability to design an engineering system or concept and to critically evaluate its feasibility