THE PROCESS OF OUTCOME-BASED EDUCATION - Implementation, Assessment and Evaluations

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Outcome-Based Education and Graduate Engineering Attributes

1.0 Introduction

With the advancement of technology, the engineering functions and markets are also continuously changing. It has become a global market place and engineers work and interact with people of different nationalities and cultural backgrounds. Engineers cross through country boundaries for business ventures and work. The multinational companies are interested to know the quality of graduates of a country as compared to certain educational standards. In order to ensure quality assurance worldwide, an International Engineering Alliance has been formed. There are three agreements known as Washington (for engineers), Dublin (for technologist) and Sidney (for technician) Accords covering mutual recognition in respect of tertiary-level qualifications in engineering. Engineers Mobility Forum was formed for the implementation of the accords. This paper define the student learning outcomes, and outlines the steps for the implementation of out-come based education, The graduate engineering attributes are compared with the ABET criteria and identify the design components in meeting the attributes of complex engineering problems.

2.0 Terminology of Program Outcomes

Learning outcomes could result from a program, a course, a chapter or a section (topic) of a chapter. In order to avoid any confusion, the learning outcomes should be defined. We will define what the students would be able to do after the completion of

- A program as program outcomes (POs) or student learning outcomes (SLOs)
- A course as course learning outcomes (CLOs)
- A chapter as chapter learning outcomes (LOs)
- A section or topic of chapter learning outcomes (Cos)

The outcomes at the completion of a program may be defined as PEOs, POs, SOs or SLOs. For example, the Malaysia Engineering Accreditation Agency [5] uses the terminology as program outcomes (POs.). The Engineering Accreditation Commission of ABET [2] uses the terminology "student outcomes" for program outcomes and the definition as follows:

> *Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge, and behaviors that students acquire as they progress through the program*

The minimum requirements for the program outcomes are normally listed by the Accreditation Agency [2-6]. Additional program outcomes may include the needs of the program's constituencies and the mission of the institution. For example, an institution may require its graduates to be entrepreneurs or global engineers, etc.

3.0 Terminology of Program Objectives

Each outcome-based education (OBE) program may decide to identify the reasons or purpose. Terms objectives or goals are generally used to identify the outcomes of an OBE program or a course.

The ABET uses the term Objective to specify the purpose of an OBE program. As an example, we will use the ABET definition [2] as follows:

> *Program educational objectives (PEOs) are broad statements that describe what graduates are expected to attain within a few years of graduation. Program educational objectives are based on the needs of the program's constituencies.*

ABET also requires that the educational objectives must be published for an easy access to the public including students and stakeholders or constituents. The educational objectives must be consistent with the mission of the institution, and the needs of the program's various constituencies. There must be a documented and effective process, involving program constituencies, for the periodic review and revision of these program educational objectives.

The PEOs are *broad* statements of the accomplishments of graduates, not what they can do and their abilities. For examples, the graduates would be known locally or nationally or internationally for their accomplishments as project engineers, project managers, design engineers, graduate or post-graduate work, business owners, consultants, recognitions for professional certification and registration, for serving on engineering and local communities, etc.

4.0 Accreditation Criteria and Process of Outcome-Based Education

The Accreditation Board for Engineering and Technology (ABET) [2] is the responsible accreditation agency in the United Sates and sets the accreditation criteria. There are similar professional agencies in Australia [3], Canada [4], Malaysia [5], United Kingdom [6], and also other countries. The OBE requirements for all of these engineering accrediting agencies are very similar. An outcome-based education (OBE) program generally includes the following activities [7]:

- Define educational objectives or goals *what graduates are expected to attain within a few years of graduation*.
- Define educational outcomes what the graduates would be able to do at the time of graduation.
- Identifying the stakeholders and their involvement in articulating and evaluating the education objectives and outcomes.
- A well-designed curriculum that will produce the desired objectives and outcomes.
- Mapping of the curricular courses how they contribute to the educational objectives and outcomes.
- Development of continuous improvement educational processes for assessing and evaluating the degree of achievements of the educational objectives and outcomes for program improvements.

5.0 ABET Curricular Requirements

The Accreditation agency generally specifies the curricular requirements. According to the ABET Engineering Accreditation Commission (EAC), the professional component must include [2]:

(a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline. Basic sciences are defined as biological, chemical, and physical sciences.
(b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other.
(c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.

What constitutes an engineering topics course? The Engineers Council for Professional Development, in the United States, defines as the creative application of “scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behaviour under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property.”

6.0 ABET Design Requirements

According to ABET, students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.

7.0 Engineering Standards

What are engineering standards? However the key is the word 'appropriate." If the project is a prototype for a potential commercial product it would have another set of design specifications such as appropriate building codes, electrical codes, water purity requirements, federal highway requirements, ISO, etc. depending on the design project. Generally students should be aware of engineering standards from professional societies: IEEE, ANSI, ASTM, SAE, etc. It is not necessary that the projects meet the standards. The projects that are sponsored by professional societies (min- Baja, SAE formula, human powered vehicle, solar powered vehicle, etc.) would have a number of appropriate standards to consider. If a project is designed for a product for people with any type of Disabilities, OSHA and ADA standards would be appropriate. Standards would generally not include terms of standard practice such as design rule of thumb, design guideline and practice, appropriate safety factors, etc. These are design tools, not standards or codes.

8.0 International Engineering Alliance

Engineering is a global business and must function in a ‘competitive’ global market place. Industries are demanding that engineering graduates must have certain skills. In order to ensure quality assurance worldwide, an International Engineering Alliance [1] has been formed with the following mission:

- Mission - working together to advance and benchmarking and mobility in the engineering profession.

There are three agreements known as *Washington*, *Dublin* and *Sidney Accords* covering mutual recognition in respect of tertiary-level qualifications in engineering.

8.1 Washington, Dublin and Sidney Accords

The *Washington Accord* signed in 1989 was the first – it recognizes substantial equivalence in the accreditation of qualifications in professional engineering, normally of four years.

The *Sydney Accord* which commenced in 2001 recognizes substantial equivalence in the accreditation of qualifications in engineering technology, normally of three years.

The *Dublin Accord* is an agreement for substantial equivalence in the accreditation of tertiary qualifications in technician engineering, normally of two years.It commenced in 2002.

8.2 Engineers Mobility Forum

Engineers Mobility Forum was formed for the implementation of the accords. The membership requires developing criteria for quality assurance and process. Members have full rights of participation in the agreement; each operates a national section of the International Professional Engineer (IntPE) register; registrants on these national sections may receive credit when seeking registration or licensure in the jurisdiction of another member.

8.3 Engineers Mobility Forum Membership

There are two types of membership: full member signatories and provisional status: Full member Signatories: They have full rights of participation in the Accord; qualifications accredited or recognized by other signatories are recognized by each signatory as being substantially equivalent to accredited or recognized qualifications within its own jurisdiction.

9.0 Washington Accord Graduate Attributes

International Engineering Alliance (IEA) specifies the program outcomes as a set of graduate attributes (GAs) for the Washington, Sydney and Dublin Accords [1]. The *Graduate attributes (GAs)* form a set of individually assessable outcomes that are the components indicative of the graduate's potential to acquire competence to practice at the appropriate level. Graduate attributes are defined for educational qualifications in the engineer, engineering technologist and engineering technician tracks. The graduate attributes serve to identify the distinctive characteristics as well as areas of commonality between the expected outcomes of the different types of programs

Washington specifies the duration of 4 years and the Knowledge profile. The graduate attributes are exemplars of the attributes expected of graduate from an accredited program. The graduate attributes are intended to assist Signatories and Provisional Members to develop outcomes-based accreditation criteria for use by their respective jurisdictions. Also, the graduate attributes guide bodies developing their accreditation systems with a view to seeking signatory status. These attributes are listed in Table 1 for engineers [1]. Therefore, it is imperative that the Engineering Accreditation Agency (IAE) of a country seeking a membership of the International Engineering Alliance should develop accreditation criteria which conform to the IEA graduate attributes. An Accreditation Agency [5] may also decide to adopt the graduate engineering attributes as the program outcome criteria.

10.0 COMPARISION OF ABET OUTCOME REQUIREMENTS AND WASHIUNGTON ACCORD ATTRIBUTES

As an example, Table 2 illustrates how the student outcomes (SOs) of the ABET Engineering Criteria [2] meet the Graduate Attributes (GAs) of the Washington Accord.

While, the knowledge attribute #11 of the Washington Accord requires the knowledge of Project Management and Finance, engineering management courses generally do not constitute engineering topics in the nomenclature of ABET unless a course does cover some engineering topics. There could be possible overlaps between the topics engineering management and industrial engineering or systems engineering. Does it means that engineering management course fall under engineering topics? Topics by topics evaluation would be needed and it calls for judgment by the evaluator.

The Washington Accord Graduate Attribute # 3 - Design/development of solutions requires - Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. Although Washington Accord does not specifically require incorporating appropriate engineering standards, but ABET does.

10.1 Complex Engineering Problems

What is a complex engineering problem? How do the ABET criteria meet the Washington Accord attributes? Table 3 lists the attributes of a complex problem solving and relates to the elements of ABET design requirements.

Table 1 International Engineering Alliance Graduate Engineering Attributes [1]

#	Knowledge	Differentiating Characteristic	… for Washington Accord Graduate
1.	Engineering Knowledge	Breadth and depth of education and type of knowledge, both theoretical and practical	Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of **complex engineering problems**
2.	Problem Analysis	Complexity of analysis	Identify, formulate, research literature and analyse ***complex*** **engineering problems** reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences
3.	Design/ development of solutions	Breadth and uniqueness of engineering problems i.e. the extent to which problems are original and to which solutions have previously been identified or codified	Design solutions for **complex engineering problems** and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations
4.	Investigation	Breadth and depth of investigation and experimentation	Conduct investigations of complex problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.
5.	Modern Tool Usage	Level of understanding of the appropriateness of the tool	Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to *complex* engineering activities, with an understanding of the limitations.
6.	The Engineer and Society	Level of knowledge and responsibility	Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice.
7.	Environment and Sustainability	Type of solutions.	Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development
8.	Ethics	Understanding and level of practice	Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.
9.	Individual and Team work	Role in and diversity of team	Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings
10.	Communication	Level of communication according to type of activities performed	Communicate effectively on ***complex*** **engineering activities** with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11.	Project Management and Finance	Level of management required for differing types of activity	Demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12.	Lifelong learning	Preparation for and depth of continuing learning.	Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

Table 2 ABET Engineering Criteria versus Washington Accord Graduate Engineering Attributes

ABET Engineering Criteria		Washington Accord	
SO#	**for 2012-2013 [2]**	**GA#**	**Graduate Attributes [1]**
(a)	an ability to apply knowledge of mathematics, science, and engineering.	1	**Engineering Knowledge:** Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution
(b)	an ability to design and conduct experiments, as well as to analyze and interpret data.	4.	**Investigation:** Conduct investigations of *complex* problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.
©	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.	3.	**Design/ development of solutions:** Design solutions for *complex* engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.
		6.	**The Engineer and Society:** Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant professional engineering practice.
(d)	an ability to function on multidisciplinary teams.	9.	**Individual and Team work:** Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.
	a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.	11.	**Project Management and Finance:** Demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments
(e)	an ability to identify, formulate, and solve engineering problems.	2.	**Problem Analysis:** Identify, formulate, research literature and analyse *complex* engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.
(f)	an understanding of professional and ethical responsibility.	8.	**Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.
(g)	an ability to communicate effectively.	10.	**Communication:** Communicate effectively on *complex* engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
(g)	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.	7.	**Environment and Sustainability:** Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development
(i)	a recognition of the need for, and an ability to engage in life-long learning.	12.	**Lifelong learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.
(j)	a knowledge of contemporary issues.	6.	**The Engineer and Society:** Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant professional engineering practice.
(k)	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	5.	**Modern Tool Usage:** Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to *complex* engineering activities, with an understanding of the limitations.

Table 3: Definition of Complex Engineering Problem

	Attribute	Complex Problems	ABET Design Component
1.	Preamble	Engineering problems which cannot be resolved without in-depth engineering knowledge, much of which is at, or informed by, the forefront of the professional discipline, and have some or all of the following characteristics listed below:	Culminating in a major design
2.	Range of conflicting requirements Involve	Involve wide-ranging or conflicting technical, engineering and other issues.	multiple realistic constraints.
3.	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	decision-making process (often iterative
4.	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	based on the knowledge and skills acquired in earlier course work
5.	Familiarity of issues	Involve infrequently encountered issues	meet desired needs.
6.	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	engineering standards
7.	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	desired needs and multiple realistic constraints.
8.	Consequences	Have significant consequences in a range of contexts.	realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (d) an ability to function on multidisciplinary
9.	Interdependence	Are high level problems including many component parts	knowledge and skills acquired in earlier course work

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