International Journal of Engineering Education Vol. 27, No. 4, pp. 859–866, 2011
Printed in Great Britain

0949-149X/91 $3.00+0.00

Developing a Rubric-Based Framework for Measuring the ABET Outcomes Achieved by Students of Electric Machinery Courses*

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Quality assurance systems of academic programs necessitate a continuous improvement process. In this process the program outcomes should be measured and assessed using a sound assessment technique. The results of the evaluation of the outcomes should then be used to develop and improve the program. Continuous assessment of the curricula outcomes is considered the cornerstone of the continuous improvement process. Previous works have presented a framework to assess and evaluate the ABET general outcomes of engineering programs. These frameworks are universal for all engineering disciplines, but they are not tailored for assessing the outcomes of a specific subject. The purpose of this paper is to assist the instructors of electric machinery courses to assess and evaluate the outcomes related to these courses. A framework has been constructed based on a rubric system for each expected outcome of the machinery courses. The suggested assessment levels are designed according to Bloom's taxonomy.

Keywords: ABET; assessment; EC-2000; outcomes; accreditation; rubric; Bloom's taxonomy

1. Introduction

The assessment of student learning outcomes plays an important role in educational effectiveness, improvement, and sustainability, which are required by accreditation organizations around the world. The ABET accreditation criteria [1] enforce the engineering programs in developing and applying a continuous improvement process. The universality and vagueness of the eleven outcomes of the engineering programs adopted by ABET has forced the engineering institutions to seek methods for making these outcomes more specific for particular programs or particular courses and to develop methods for evaluating their students according to these outcomes.

The ABET Accreditation Criteria with its list of eleven outcomes (see the Appendix) moved the accreditation focus from 'what are you [the program] doing? to 'What are your students doing? This means that the major requirement is the implementation of a continuous improvement process that enables these outcomes to be measured, evaluated, and the results fed back to the program designers to be used for improving the program. Consequently, a continuous assessment of the curricula outcomes is considered the cornerstone of the continuous improvement process. This will force the faculty to inspect the methods of assessment that are currently used, and to seek new methodologies for ongoing assessment for the outcomes of each subject. However, the faculty usually faces difficulties in constructing a well-documented process for assessment and evaluation with a clear path for revision based on the evaluation results.

In literature some of continuous improvement models proposing an ideal educational process have been presented [2–4]. Such models have exposed the engineering faculty to a cycle in which the educational process is first defined, measured, compared to desired criteria or standards, and subsequently improved, and then the cycle is repeated. Also, the faculty should ensure that the program outcomes serve the mission and the objectives of the institution. The program outcomes should be measured and assessed using a sound assessment system, and must provide evidence that the results of the evaluation have been applied to develop and improve the program. There are a variety of studies that show how the engineering departments can respond to the ABET Criteria. In this respect, Ahlgren and Palladino [5] developed a comprehensive, sustainable set of assessment tools to measure the achievement of the stated objectives and outcomes in the Trinity College of Engineering. Carlson *et al.* [6] presented a description of a comprehensive assessment plan that was applied on the Mechatronics course at the University of Detroit Mercy. Davis *et al.* [7] presented a formalized course assessment process that was implemented by the Citadel Department of Civil and Environmental Engineering. Brumm *et al.* [8] presented a competency-based outcomes assessment system for the Agricultural Engineering Program at Iowa State University. Yue [9] presented a course-based approach that correlates learning outcome objectives with accreditation standards.

* Accepted 20 March 2011.

Abu-Jdayil and Al-Attar [10] discussed the direct assessment methods used in the Chemical Engineering Program for a continuous improvement process at the United Arab Emirates University.

In previous works [5–10], where different assessment processes were used for measuring the program outcomes there is no method for measuring the ABET outcomes achieved by specific courses. Besterfield-Sacre *et al.* [11] presented a universal framework for all the eleven ABET outcomes. They divided each single outcome into a set of attributes. Also, Mead and Bennett [12] presented a similar framework for all the eleven ABET outcomes. These two frameworks are considered universal for all engineering disciplines. Applying these frameworks to the outcomes of the courses of a particular subject often poses some difficulties, and it is not a direct process.

The objective of the present paper is to construct a framework for measuring the extent of achieving the ABET outcomes in students of electrical machine courses. The assessment framework has been constructed in a rubric form, which consists of six education levels according to Bloom's taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation) [13].

2. Identifying the student learning outcomes

Student learning outcomes may be defined as descriptions of what academic departments (faculty) want students to know (cognitive), think (attitudinal), or do (behavioral) when they have complete their program, as well as their general education or 'core' curriculum [14].

The eleven ABET outcomes serve as a foundation for all engineering programs, hence each program must define itself by adding its own specificity to the outcomes. The lack of specificity possesses two problems. First, faculty consensus is required if successful implementation is to be followed. This consensus must encompass definitions, performance criteria, and assessment processes [15]. If faculty cannot make connections across courses, it will be difficult to transfer knowledge, behavior, and attitudes across the curriculum. Secondly, in order to recast each outcome properly into measurable descriptions that will result in usable assessment results, sufficient expertise, resources, and time are required [11]. Hence, a working definition of student learning outcomes (relevant to engineering education) is needed to evaluate engineering programs properly. It is proposed that student learning outcomes are observable and measurable manifestations of applied knowledge [11].

Usually, in any electrical engineering discipline there are no more than two electrical machine courses. The laboratory course may be included in these two courses or separated in a stand alone course.

Electrical machines is a subject where students deal with various types of electrical machines that are employed in industry, power stations, domestic and commercial appliances, etc. Electrical machines mainly fall into four categories: transformers, induction machines, synchronous machines and DC machines. In electrical machine courses, the students learn the concepts, principles of operation, performance characteristics and methods of control of most of the various types of electrical machines. The electrical machines laboratory supports the teaching process, allowing the students to do hands-on experiments with real machines and giving them the capability of performing major tests on the electrical machines.

The plan of the Electrical Engineering program in Qassim Engineering College (QEC) contains two electrical machine courses each is 3 credit hours and one laboratory course of 1 credit hour. The building

Table 1. Outcomes / Sub-outcomes table

Outcome	Sub-outcome
a. An ability to apply knowledge of mathematics, science, and engineering	a.1 applying knowledge of mathematics a.2 applying knowledge of science and engineering
b. An ability to design and conduct experiments, as well as being able to analyze and interpret data	b.1 Designing experiments b.2 Conducting experiments b.3 Analyzing data b.4 Interpreting data
e. An ability to identify, formulate, and solve engineering problems	e.1 Identifying problem e.2 Formulate the problem statement e.3 Solving the problem
g. An ability to communicate effectively	g.1 Orally communication skills g.2 Written communication skills g.3 Visual communication skills
k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	

of the assessment system has been started by the electrical machines senior faculty in QEC with an investigation of the contents of these courses in order to determine the ABET related outcomes. Their consensus was that specific ABET outcomes, namely; a, b, e, g and k are greatly expected from the electrical machine courses (see the Appendix). These five outcomes are broad outcomes. For precise assessment, these outcomes should be expanded into sets of sub-outcomes as shown in Table 1.

3. Development of the rubric-based framework

A rubric is a series of narrative statements describing the levels of performance. It is a set of criteria and standards linked to learning outcomes that are used to assess a student's performance [16]. Generally, the rubric specifies the level of performance expected for several levels of quality. These levels of quality may be specified using different ratings (e.g., Excellent, Good, Needs Improvement) or using numerical scores (e.g., 4, 3, 2, 1). A rubric-based framework using Bloom's taxonomy has been developed for accurate assessment of the sub-outcomes illustrated in Table 1. In the present framework, the rubric is designed depending on the educational levels of Bloom's taxonomy [13]. Bloom's taxonomy is based on six levels of the cognitive domain: knowledge, comprehension, application, analysis, synthesis, and evaluation as shown in Table 2. Bloom's taxonomy is used here as the basis for a framework that describes the individual sub-outcomes. The use of the Bloom's taxonomy of the cognitive domain can be very helpful in facilitating discussion among engineering educators about the outcomes and their associated sub-outcomes.

Using the sub-outcomes illustrated in Table 1 and the Bloom's education levels and their related verbs shown in Table 2 a rubric framework has been developed as shown in Table 3. The table shows the expanded sub-outcomes and their definitions along with operational verbs of Bloom's taxonomy for each particular sub-outcome. It is important to note that within some of sub-outcomes not all of Bloom's levels are represented. A sub-outcome may have no description identified for a certain Bloom's level. This depends on the nature of the sub-outcome itself. For example, the analysis level and synthesis level are not applicable for sub-outcomes (b.2 and g.1).

4. The assessment criteria

As is clear from Table 3, the assessment framework consists of six learning levels. At the end of the machine courses, the student should have reached a certain level of learning for each sub-outcome. The question is: At what level can it be said that the student has satisfied the specific sub-outcome? In the engineering field the required behavior is seen as the application of what the student has learned. Behavioral aspects are those skills that engineering students possess, and true learning should be reflected through the actions and behavior of the student. The cognitive processes or attitudes of students can not be separated from their behavior. This means that true learning can not be measured without observable behavior. Each of the ABET outcomes should reflect the integration of the cognitive and behavioral (the knowing and doing). So, we think that the 3rd level (application domain) in the assessment framework is enough—for undergraduate students—to say that the student has satisfied the specific sub-outcome if he practiced at least one of the descriptions illustrated under the 3rd level. The genius students or graduates students

Table 2. Bloom's taxonomy [12, 13]

Bloom's domains	Bloom's definition	Key words (descriptive verbs)
Knowledge	Remembering previously learned information	Define, label, listen, list, memorize, name, read, recall, record, relate, repeat, view
Comprehension	Grasping the meaning of information	Describe, discuss, explain, express, identify, locate, recognize, report, restate, review, solve, tell
Application	Applying knowledge to actual situations	Apply, demonstrate, employ, illustrate, interpret, operate, practice, recognize, solve, use
Analysis	Breaking down objects or ideas into simpler parts and determines the relation among them	Analyze, appraise, break apart, break down. calculate, compare, contrast, debate, diagram, differentiate, examine, experiment, explain, inspect, inventory, question, relate, solve
Synthesis	Rearranging small ideas or components into a new whole	Arrange, assemble, collect, compose, construct, create, design, formulate, manage, organize, plan, prepare, propose, set up, write
Evaluation	The ability to judge and appreciate the value of ideas, concepts, theories or solution methods using appropriate criteria	Appraise, assess, choose, compare, estimate (quality), evaluate, judge, predict (quality), rate, value, select

Table 3. The assessment framework based on Bloom's education levels

a.1 applying knowledge of mathematics	
Knowledge	• Knows, recognizes or describe the mathematical relations that governs the electrical machines
Comprehension	• Understands the properties of mathematical relations related to electrical machines • Distinguishes between the different mathematical electrical machines' relations and classifies them
Application	• Uses mathematical relations related to electrical machines in the right way • Calculates the performance and parameters of electrical machines • Chooses the appropriate mathematical model for each case
Analysis	• Can break down the mathematical relations related to electrical machines into simpler relations to see how they are combined • Interprets the results of mathematical models or relations
Synthesis	• Can combine simple mathematical relations to formulate new models or relations
Evaluation	• Can evaluate the validity of mathematical relations or models • Estimates the accuracy of mathematical models
a.2 applying knowledge of science and engineering	
Knowledge	• Describes fundamental of scientific or engineering principles of the electrical machines
Comprehension	• Recognizes the scientific or engineering principles that affect certain performance of electrical machines • Explains the scientific or engineering principles that affect certain performance of electrical machines
Application	• Applies scientific and engineering principles to obtain the performance of electrical machines or to solve problems related to electrical machines
Analysis	• Uses scientific and engineering principles to analyze data or to compare the results • Distinguishes between different characteristics of electrical machines
Synthesis	• Uses scientific and engineering principles to design or develop electrical machines • Uses scientific and engineering principles to develop mathematical models for electrical machines
Evaluation	• Uses scientific and engineering principles to evaluate the validity of using specific type of electrical machines for certain application • Evaluates different models of electrical machines depending on their performance characteristics
b.1 Designing experiments	
Knowledge	• Knows or lists the major experiments related to electrical machines
Comprehension	• Describes the major experiments related to electrical machines • Distinguishes between different experiments • Identifies the constraints of experiments • Selects appropriate equipments or testing apparatus
Application	• Determines the purpose of experiment • Determines the steps of implementation • Uses the correct theory • Determines the constraints and assumptions • Determines the ratings of needed equipments and their setup values.
Analysis	Not applicable
Synthesis	Not applicable
Evaluation	Evaluates the validity of designed experiment for certain purpose
b.2 Conducting experiments	
Knowledge	Not applicable
Comprehension	• Understands methods of measurements • Understands methods of data collection • Aware in the measurement errors • Understands the connection methods of equipments and apparatus • Understands method of operation (experiment steps) • Understand the risk of experiment and the precautions should be taken
Application	• Uses appropriate techniques to collect data • Uses modern measurement instruments • Connects equipments and apparatus correctly • Implements the experiment in correct manner • Applies the safety precautions correctly
Analysis	Not applicable
Synthesis	Not applicable
Evaluation	Not applicable
b.3 Analyzing data	
Knowledge	• Lists or names different methods of data analysis • Names some data analysis software
Comprehension	• Explains some methods of data analysis • Selects appropriate method of data analysis • Understands the differences between different methods of data analysis
Application	• Uses a appropriate method of data analysis • Uses some software for data analysis • Uses appropriate instruments for data analysis
Analysis	• Analyzes the methods used in data analysis
Synthesis	• Composes more than one method of data analysis • Integrates more than one instrument for data analysis • Integrates theoretical and experimental methods of data analysis
• Evaluation	• Evaluates the methods used in data analysis • Evaluates the tools or software used for data analysis

Table 3. *Continued*

b.4 Interpreting data	
Knowledge	• Aware for the necessity of data interpreting
Comprehension	• Understands the causes behind the differences between the theory and actual results • Understands the impact of assumptions on the accuracy of results
Application	• Verifies and validates the experimental results • Determines the feasible range of operation • Detects the unusual or un logical results • Uses theoretical concepts to interpret the results
Analysis	• Asks where the constraints hold in both experimental and actual world • Separates the important data from others • Classifies the results in categories
Synthesis	• Combines results of multiple experiments • Presents results in a suitable format (graph, plot, table, chart)
Evaluation	• Evaluates the approaches used in data interpreting • Evaluates the feasibility of the interpreted information
e.1 Identifying problems	
Knowledge	• Knows the methods used in diagnosing problems • Recalls similar problems
Comprehension	• Selects appropriate diagnosing methods • Asks questions to collect information about the problem • Distinguishes what is known and unknown about the problem
Application	• Uses appropriate diagnosing method or instrument • Applies a suitable test to identify the problem • Tries different modes of operation to identify the problem
Analysis	• Analyzes the collected data or results of tests to determine the problem
Synthesis	• Combines the observations and collected data together or with results of tests to determine the problem
Evaluation	• Evaluates the methods used in problems identifications
e.2 Formulate the problem statement	
Knowledge	• Describes the problem to be solved • Knows the method of problem definition • Know the methods of information gathering
Comprehension	• Visualize the problem through sketches or diagrams • Outlines the variables and constraints of the problem • Determines the boundaries and restrictions of the problem • Selects the useful information to be used in the problem statement
Application	• States the problem in words where the definition includes all pieces of the problem and all constraints
Analysis	• Isolates key aspects of the problem • Analyzes potential problem variables or constraints for inclusion in the problem statement • Separates between facts, assumptions and opinions
Synthesis	• Combines and relates variables and constraints into problem statement
Evaluation	• Evaluates the final statement of problem
e.3 Solving the problems	
Knowledge	• Specifies the problem scope • Recognizes the approaches of problem solving • Indicates how theory can be applied in the practice • Cites appropriate resources of information • Identifies the relevant engineering, math or science principles
Comprehension	• Identifies applicable engineering principles necessary for solving the problem • Discusses the applicable mathematical and science principles related to the problem • Describes the relation among the physical model and the underlying principles
Application	• Uses knowledge base to develop possible approaches • Formulates a model with appropriate scope and level of details • Formulates appropriate hypothesis to create mathematical or physical model • Uses theoretical concepts to develop solutions • Uses computational or simulation methods for obtaining solution • Generates possible solutions for given problem
Analysis	• Examines approaches in order to select the more efficient one • Balances level of difficulty and accuracy needed • Select appropriate solution or experimentation methodology • Determines the robustness of solution • Uses knowledge, information and judgment to rank or select the best solution
Synthesis	• Generates potential alternatives or ideas to solve the problem • Combines sub-solutions in order to obtain the overall solution • Develops algorithms or heuristics to obtain solutions • Assembles a collection of solutions that adhere to the given solution criterion
Evaluation	• Evaluates the feasibility of the final solution

Table 3. *Continued*

g.1 Oral communication skills	
Knowledge	• Knows the skills of exchange the information or ideas effectively
Comprehension	• Can list some of oral communication skills • Can choose appropriate skill for certain situation
Application	• Practices some of oral communication skills such as: listening skills, body language, eye contacts, avoids communication roadblocks, seeks first to understand, seeks first the intersection points, gives constructive feedback.
Analysis	Not applicable
Synthesis	Not applicable
Evaluation	Not applicable
g.2 Written communication skills	
Knowledge	• Knows the skills of professional report writing .
Comprehension	• Write reports with acceptable format (include informative cover page, readable work, neat and clean work, use numbering marks).
Application	• Uses certain template such presentation sandwich (Introduction, Main work, Conclusion) – In the introduction (context) the reader should be oriented about what will come and what the purpose is. – In the main work the explanation should be clear for others and includes sketches, plots, tables, charts and the terms or variables should be well defined. – In the conclusion (discussion) the end of work should be clear in addition to summary about what was achieved or what the process used and what may happen next.
Analysis	Not applicable
Synthesis	Not applicable
Evaluation	Not applicable
g.3 Visual communication skills	
Knowledge	• Knows the equipments and software needed for visual presentation
Comprehension	• Outlines the differences or advantages and disadvantages of some of equipments and software used in visual presentation. • Understands what is the purpose of each piece of equipment or software used in visual presentation.
Application	• Uses sandwich format in their visual presentation • Uses Visualization means or programs as needed such as: • data show, projector, players, charts, photos, presentation programs, video or photos editing programs, drawing programs, etc.
Analysis	Not applicable
Synthesis	Not applicable
Evaluation	Not applicable
k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	
Knowledge	• Lists available techniques, skills and tools related to electrical machines such as computer software, simulation packages, diagnostic equipment
Comprehension	• Classifies the function of each technique, skill or tool according to: – Identifying and solving problems. – Studying the performance – Developing a design • Selects appropriate technique or tool for a specific engineering task
Application	• Uses engineering techniques, skills and tools including computers to identify and solve engineering problems related to electrical machines • Uses engineering techniques, skills and tools including computers to study performance of electrical machines • Uses engineering techniques, skills and tools including computers to collect data needed for solving problems related to electrical machines
Analysis	• Compares results from several engineering tools to determine the best result compatible with real case • Chooses which techniques or tools are most appropriate to complete a specific engineering task
Synthesis	• Combines the use of two or more tools or techniques to solve engineering problems related to electrical machines • Combines results from several sources such as calculation methods, graphical analysis, experimental work and computer simulation to achieve the best solution
Evaluation	• Can evaluate different techniques, tools, software or simulation packages depending on their theory of operation or the accuracy of their results

may satisfy levels above the 3rd level (application level).

A student may fail to satisfy all sub-outcomes related to a certain outcome. In this case the student doesn't satisfy this outcome in the Electrical machine subject, but he or she still has a chance to satisfy this outcome in other courses, as the ABET outcomes are measured by the time of graduation.

5. The application methodology

The proposed framework may be applied to two levels of assessment: student assessment and course assessment. In student assessment, the assessment process should be applied to each individual student to measure their degrees of achievement in these five outcomes while, in the course assessment, the assessment process should be applied to a random sample of students of different grades to determine to what level the outcomes of electrical machine courses are satisfied. In both levels, all the evaluation materials produced by students during these courses such as midterm and final exams, quizzes, homework, presentations, laboratory reports, etc. should be used in the assessment process. The assessor, who may be the course instructor, takes a rubric sheet for each student to be assessed then examines the student work and determines the appropriate level of performance using the rubric based framework. The assessment process may be easier if the student's evaluation materials were prepared according to the proposed framework.

6. Conclusions

In this work an assessment framework has been developed for measuring the extent to which the ABET outcomes are achieved in students of electrical machine courses. The assessment framework was constructed in a rubric form that consists of six education levels according to Bloom's taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation). Of the eleven ABET outcomes, five outcomes were determined as the outcomes most related to electrical machine courses. These five outcomes are then divided into small sub-outcomes for precise evaluation. The third level of Bloom's taxonomy (application) has been adopted as an indicator for achieving the specified sub-outcome. The assessment framework may be applied to two levels of assessment: student assessment and course assessment. The idea of the proposed framework may be applied for constructing similar frameworks for evaluating other courses once the related outcomes have been determined.

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Appendix

The program outcomes as stated in '*Abet Criteria for Accrediting Engineering Programs,* see: http://www.abet.org

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.

Program outcomes are outcomes (a) through (k) plus any additional outcomes that may be articulated by the program. Program outcomes must foster attainment of program educational objectives.

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