المركز الوطني للقياس والتقويم في التعليم العالي
National Center for Assessment in Higher Education

National Center for Assessment in Higher Education (QIYAS)

Framework for Assessing Learning Outcomes in Engineering

(Mechanical Engineering)

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1. INTRODUCTION, BACKGROUND AND FRAMEWORK STRUCTURE

1.1 Introduction

The Ministry of Higher Education in Saudi Arabia has recently requested the National Center for Assessment in Higher Education (QIYAS) to launch an ambitious project to develop a comprehensive framework for assessing Learning Outcomes (LOs) in Engineering Education (Phase 1) and to subsequently prepare a unified engineering qualification exam based on the developed framework (Phase 2). The project covered the following areas of engineering education: Chemical, Civil, Computer, Electrical, Industrial, Mechanical, in addition to Architectural Engineering. In the first phase of this project, a multi-disciplinary team composed of university professors and experts from QIYAS was formed to develop the learning outcomes framework. During the work in this phase, the team interacted with many national and international institutions and experts. The team also reviewed available approaches and methodologies related to the development of frameworks for learning outcomes in engineering education. The review covered experiences from various countries worldwide including North America, Europe, Australia, New Zeeland, Japan, Singapore, China, Korea, Malaysia and South Africa. The review also covered independent and important projects on learning outcomes such as the Accreditation Board for Engineering and Technology (ABET) in the United States [1], Engineers Australia (EA) [2], European Network for Accreditation of Engineering Education (EUR-ACE) [3], The UK Standard for Professional Engineering Competence (UK-SPEC) [4], Conceiving-Designing-Implementing-Operating (CDIO) initiative [5], Tuning-AHELO framework [6] and the National Architectural Accrediting Board (NAAB) [7]. In addition, two workshops were conducted at the QIYAS Center, to review the outcomes of the study. The first workshop was attended by high ranking officials from the Ministry of Higher Education and by several international experts on engineering education and development of learning outcomes. The second workshop was attended by representatives of various local universities who presented their detailed comments on the framework.

1.2 Background on Learning Outcomes

The current international trends in education are showing a shift from the traditional teacher-centered approach to a student-centered approach. The teacher-centered approach focuses essentially on the teacher's input. Among the criticisms of this type of approach is that it can be difficult to identify precisely what the student has to be able to do in order to pass the course or program [8]. The alternative student-centered (or outcome-based) approach focuses on what the students are expected to be able to do at the end of the course or program [8]. Statements called learning outcomes are used to express what a learner is expected to know, understand and/or be able to demonstrate after completion of a process of learning [9]. Learning outcomes have strong implications on curriculum design, teaching, learning and assessment, as well as quality assurance. Engineering education is in the forefront of areas that should benefit from the student-centered approach. The Engineering education environment is changing as information and communication technologies are having greater impact, and innovation is becoming increasingly essential. The future role of engineering requires that non-technical skills should be added to the technical dimension of engineering education.

Moreover, in today's competitive environment, the assessment of learning outcomes has become a primary focus for engineering education worldwide. Employers as well as academic accreditation entities push for the incorporation of sound assessment techniques into engineering programs. The outcome-driven assessment process, if carefully designed and implemented, can be useful at different levels; (1) It can provide useful information on whether graduates have acquired the knowledge and skills defined by predetermined educational objectives; (2) It can also convey useful information to faculty and administrators on the effectiveness of the design and delivery of the educational program; (3) It can also develop, in the long term, instruments to obtain comparable information on what students actually learn across different engineering colleges [8 -10].

The assessment of learning outcomes is particularly important to the Kingdom higher educational institutes. The Kingdom has recognized the need to move from a natural resource-based economy to a knowledge-based economy, which puts new priority on the role of universities in general and engineering colleges, in particular. Saudi's young engineering generation will need to acquire new skills and capabilities to meet the current diversification objectives and to be competitive with the best students from anywhere in the world. The proposed assessment framework will ensure that acceptable educational standards are fulfilled by public as well as private universities.

1.3 Structure of the Proposed Framework

One of the unique and innovative features of the developed framework is the hierarchy (multi-level) structure used in specifying the learning outcomes as well as the level of comprehensiveness which covers both the discipline and sub-discipline levels. As illustrated in Figure 1, four hierarchy levels are covered in the developed Framework of Engineering Learning Outcomes, namely:

1) **General Skills**, which cover learning outcomes for any higher education graduate (engineering or otherwise). General skills or generic skills also referred to as transferable or soft skills, address the basic competencies that all higher education graduates, including engineering graduates, ought to possess upon their graduation.
2) **Engineering Skills**, which cover learning outcomes for any engineering graduate regardless of his/her general specialty (discipline).
3) **Discipline-level Engineering Skills**, which cover learning outcomes for a given engineering specialty (Chemical Engineering, Civil Engineering, Computer Engineering, Industrial Engineering, Electrical Engineering, Architectural Engineering, and Mechanical Engineering)

4) **Sub-discipline-level Engineering Skills**, which cover learning outcomes for a given engineering specific specialty (Electronics Engineering, Materials Science and Engineering, Thermal and Desalination Engineering, Structural Engineering, Manufacturing systems engineering, Computer Networks, etc.)

In setting up the learning outcomes for General Engineering and for specific disciplines, the four key learning areas namely **Basic Sciences & Engineering Fundamentals**, **Engineering Analysis and Investigation, Engineering Design,** and **Engineering Practice** were considered. The proposed Learning outcomes were formulated using the revised Bloom taxonomy in the cognitive level (Remembering, Understanding, Applying, Analyzing, Evaluating and Creating) given in the Appendix.

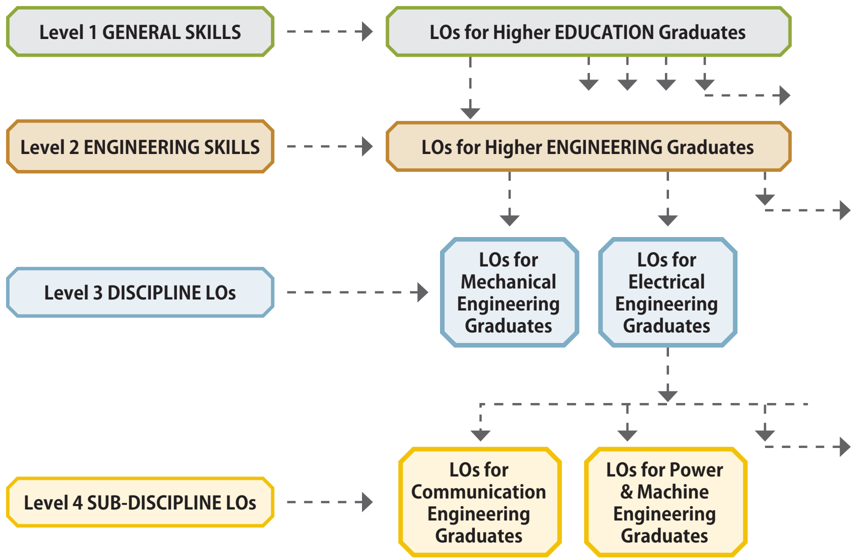

Fig. 1 Hierarchy levels of QIYAS Framework of Engineering Learning Outcomes

2. MECHANICAL ENGINEERING LEARNING OUTCOMES (ME)

2.1 Discipline Level Learning Outcomes

Mechanical Engineering **(ME)** skills include the knowledge of the fundamentals of various mechanical engineering principal areas, namely materials, solid mechanics, and manufacturing, dynamics and control, fluid mechanics, thermal sciences including thermodynamics and heat transfer, and design. Mechanical engineering graduates should be able to build on their acquired skills pertaining to basic sciences and engineering fundamentals, engineering analysis and investigation, engineering design, and engineering practice skills, and consequently acquire mechanical engineering discipline-level skills. Mechanical engineering graduates should be able to apply the general engineering skills and principles of mechanical engineering on modeling, analyzing, designing, and realizing physical systems, components, or processes in both mechanical and thermal systems areas.

The following is the list of discipline related abilities, denoted by (DME#) and under each ability there is a set of learning outcomes associated with the ability.

2.1.1 Engineering Sciences

DME1.The ability to apply knowledge of engineering sciences, including physics and chemistry, as well as the theoretical and analytical basis of generic mechanical and thermal systems, and to formulate the governing equations and formulas with proper interpretation of the associated physical phenomena which determine the behaviors of such systems

Learning Outcomes

Graduates who possess this ability should be able to:

1. Discuss the fundamentals of engineering materials, their significance, classification and diverse applications, different level of structures (atomic, crystal, and microscopic), and the effect of different heat treatment and processing on various alloys to tailor and achieve a required microstructure
2. Explain the fundamentals and basic concepts associated with mechanics of solids, including equilibrium of force systems, moments and couples, friction, concepts of stress and strains, deformations and internal stresses associated with external loadings, stress concentration factors, residual stresses, deflection and stiffness, stability and buckling, and failure theories under steady and variable loadings
3. Describe the basic manufacturing processes, including metal casting processes and equipment, expandable mould casting processes, metal forming processes, machining processes, and joining and assembly processes
4. Describe the fundamentals, physical meaning, and governing equations of dynamics and control, including kinematics and kinetics of particles and rigid bodies, Newton's laws, work-energy, impulse-momentum, D'Alembert's principle, kinematics and dynamics of mechanisms, cams and followers, balancing of rigid rotors, ordinary and planetary gear trains, and basic concepts of automatic control
5. Describe the fundamentals, physical meaning and governing phenomena of fluid mechanics, including conservation of mass and balance of momentum for fluid flow situations, dimensional analysis and similarity considerations, boundary layer and drag, momentum flux through a control volume, and losses of pressure in pipes and other configurations
6. Apply knowledge of advanced mathematics as well as engineering sciences to understand the basic phenomena and concepts associated with thermal systems, including first and second law of thermodynamics, entropy, energy destruction, energy balance, and basic modes of heat transfer

2.1.2 Engineering Analysis and Investigation

DME2. The ability to solve, with proper notation, and analyze mechanical and thermal systems, components or processes using efficient and effective techniques and established methods

Learning Outcomes

Graduates who possess this ability should be able to:

1. Analyze different microstructures of engineering materials
2. Quantify the internal stresses and strains, and deformations that are associated with combined loading conditions
3. Select manufacturing processes to produce the desired products based on the technological characteristics, quality and cost.
4. Quantify tool life, cutting forces and power consumed in various cutting processes
5. Analyze forces, power and work done in various deformation processes
6. Solve particle and rigid body dynamics problems with the ability to visualize physical configuration
7. Analyze mechanism position, velocity, and acceleration graphically by solving relative vector equations and using velocity and acceleration polygons
8. Solve the inverse dynamic problem to calculate the internal forces, the motor driving force, and the shaking forces at the supports
9. Apply analytical methods for analysis of mechanisms
10. Examine and analyze the dynamics and control of mechanical, hydraulic, pneumatic, thermal, and electric systems using mathematical techniques, time domain and frequency domain analyses, as well as graphical interpretation methods, including bode plots and root locus

11. Specify performance objectives of the dynamic systems in time and frequency domain and analyze linear system stability
12. Analyze the stability of a floating body
13. Examine fluid flow problems using continuity, momentum, and energy principles
14. Classify flow behavior and apply the proper principles for analysis
15. Solve fluid flow problems using similarity
16. Use second law of thermodynamics, principles of conservation of mass, and conservation of energy to solve thermodynamic problems
17. Examine the performance of vapor power and gas power cycles
18. Quantify heat, work, entropy change, or energy destruction associated with a process undertaken by a mixture of ideal/ real gases
19. Perform steady-state conduction in rectangular, cylindrical and spherical systems without and with heat generation
20. Analyze conduction problems under time-dependent conditions
21. Apply various empirical correlations for forced and natural convection to different flow situations
22. Assess thermal-fluid processes and systems such as: piping networks, and performance characteristics of pumps, compressors and fans

2.1.3 Engineering Design

DME3.The ability to design and realize mechanical and thermal systems, components, products or processes to meet specific needs while observing technical, environmental, economical, societal, ethical, safety, sustainability, and manufacturability constraints

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply the basic design of mechanical elements to achieve satisfactory levels

of safety, including shafts, screws and fasteners, joining components, springs, gears, brakes and clutches, flexible elements, rolling element bearings, and Journal Bearings

2. Select from standard tables and catalogues machine elements, components, and materials given appropriate performance requirements
3. Synthesize a linkage for specified function or motion generation
4. Design follower motion, and layout cam profile for the synthesized motion
5. Design controllers to improve processes and systems to accomplish desired objectives
6. Recognize the basic design, classification, and construction features of heat exchangers
7. Use the knowledge of thermodynamics, heat transfer and fluid mechanics in the design of integrated thermal systems and selection of thermal-fluid components such as pumps, fans, and compressors based on specified performance
8. Integrate customer requirements and design specifications in the fabrication and/or construction of devices, components, products, and systems as well as identify target clients and establish innovative solutions to open-ended mechanical engineering problems while dealing with limitations, uncertainties, safety and cost effectiveness factors

DME4.The ability to conceive, design, and operate conceptual prototypes and laboratory-scale of mechanical and thermal systems, components or processes

Learning Outcomes

Graduates who possess this ability should be able to:

1. Conduct laboratory experiments and/or field tests on mechanical and thermal systems, components or processes
2. Use analytic and laboratory experimental tools as well as engineering application

software to help in the design process as well as incorporate basic concepts of probability theory to handle uncertainty associated with the design of components and systems

3. Develop several alternative design concepts of designing physical systems, components or processes, appraise merits and drawbacks of alternate design scenarios concerning efficiency, human factors, reliability, aesthetics, etc., and assess the product compliance with relevant specifications and standards while realizing the impacts on environment, society, and depletion of natural recourses

2.1.4 Engineering Practice

DME5.The ability to recognize, distinguish, and select mechanical installations, equipment, and systems in both laboratory environment and practical engineering setups

Learning Outcomes

Graduates who possess this ability should be able to:

1. Establish familiarity with components, measuring devices and equipment in mechanical and thermal laboratory environments, including oscilloscopes, voltage and current sources, amplifiers, spectrum analyzers, transducers, analog to digital converters, and signal conditioning units
2. Recognize mechanical installations and equipment in real life situations, including pumps, fans, compressors, engines, turbines, machines, and electric motors

DME6. The ability to use modern engineering tools, methods, and techniques that are necessary for engineering practice

Learning Outcomes

Graduates who possess this ability should be able to:

1. Use control methods to improve processes and systems
2. Apply appropriate manufacturing processes

2.2 Sub-discipline #1: Production and Design Engineering

This sub-discipline is concerned with the design, manufacturing, and control of mechanical systems, as well as their subsystems and components. It encompasses three main scientific fields: machine design, manufacturing engineering, and applied mechanics. Production and design engineering graduates should be able to build on their acquired knowledge and skills pertaining to basic discipline-level mechanical engineering learning in order to understand, analyze, synthesize, design, and realize products and equipment, and the environment and tools required for their manufacture.

2.2.1 Engineering Sciences

DME_S1_1. The ability to define and model manufacturing systems and their components by applying manufacturing engineering sciences and tools

Learning Outcomes

Graduates who possess this ability should be able to:

1. Discuss the fundamentals of heat treatment of metals, and metal powders and ceramics
2. Apply the principles of cutting mechanisms, tool materials and geometry, cutting tools assembly techniques, and material removal operations
3. Apply the principles of metrology and quality control on manufacturing processes, including standardization and standards, accuracy and precision, errors, geometric tolerances, surface texture, quality control and sampling

techniques, quality assurance systems, and total quality management

4. Apply the fundamentals of process control, control theory principles, and digital control using programmable logic controller and computer
5. Apply the principles of computer aided process planning, and computer-integrated manufacturing systems
6. Explain manufacturing planning including production methods and machine capacities
7. Use the principles of labor cost and material cost analyses

DME_S1_2. The ability to combine technical knowledge and skills from manufacturing engineering sciences to evaluate and monitor manufacturing system performance

Learning Outcomes

Graduates who possess this ability should be able to:

1. Discuss the fundamentals of manufacturing systems
2. Discuss manufacturing organizations including group technology, job-shop, assembly lines manufacturing, inventory philosophies, work environment, work simplification, and process flow analysis
3. Describe the behavior and properties of engineering materials as they are influenced by various manufacturing processes
4. Analyze engineering materials processing parameters that influence product quality, and production costs
5. Describe the fundamentals, physical meaning, and governing equations of mechanical vibrations
6. Explain the principles and tools necessary for fault diagnosis of mechanical systems

2.2.2 Engineering Analysis and Investigation

DME_S1_3. The ability to analyze, solve, and implement effective solutions to realistic problems in the manufacturing systems by applying manufacturing engineering tools, contemporary knowledge and cutting-edge technologies.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply the principles of computer aided engineering on the manufacturing problems, including solid modeling, CAD packages, finite element technique, thermal analysis, and optimization
2. Analyze manufacturing operations using statistical methods and information technology
3. Apply different techniques of analysis (energy method, slab method, and upper bound method) to estimate the load required to initiate plastic deformation
4. Analyze the effects of cutting parameters on machining operations
5. Perform estimation of the operation cost, product cost, and product pricing
6. Apply the fundamentals of high volume manufacturing systems analysis
7. Apply the basics of engineering analysis in manfuctature engineering decisions, project control, and forecasting, decisions tree analysis, production planning
8. Solve steady state thermal problems and pressure vessels problems using finite element method
9. Analyze the free and forced vibrations of single and multidegree of freedom systems using Matlab software
10. Model and analyze simple continous vibrational systems including approximate solution methods

2.2.3 Engineering Design

DME_S1_4. The ability to conceive and design various components of manufacturing system, to meet specific needs while observing reasonable constraints such as sustainability, quality, safety, social, economic, environmental, political, ethical and manufacturability.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Integrate the design of products and equipment with the necessary manufacturing environment and tooling
2. Apply the fundamentals of design of high volume manufacturing systems
3. Design facility layout and allocations by applying the principles of plant layout, area allocation and space analysis and flow analysis
4. Design lean manufacturing systems
5. Design effective vibration isolation systems and vibration absorbers

2.2.4 Engineering Practice

DME_S1_5. Ability to measure manufacturing process parameters in manufacturing laboratory and deduce technical information about the process

Learning Outcomes

Graduates who possess this ability should be able to:

1. Analyze and interpret engineering experimental data and output information from experiments at the manufacturing engineering laboratories.

2.3 Sub-discipline #2: Thermal and Desalination Engineering

This sub-discipline is concerned with thermal engineering applications. It includes energy conversion systems, refrigeration and air-conditioning, and saline water conversion. Thermal and desalination engineering graduates should be able to build on their acquired knowledge and skills pertaining to basic discipline-level mechanical engineering learning in order to work professionally in both thermal and mechanical engineering areas.

2.3.1 Engineering Sciences

DME_S2_1. The ability to demonstrate advanced knowledge of the subject-specific fundamentals of thermal and desalination engineering

Learning Outcomes

Graduates who possess this ability should be able to:

1. Discuss the fundamentals of fluid flow and heat transmission
2. Classify the different types of heat exchangers
3. Describe the principles and operations of power plants, their overall performance and economics
4. Describe the principles and operations of turbo-machinery and gas turbines
5. Explain the fundamentals of the internal combustion engines
6. Discuss the fundamentals of refrigeration and air conditioning
7. Discuss the characteristics of sea and brackish water
8. Explain the different types of conventional and non-conventional desalination technologies
9. Report on the different renewable energy resources that can be used in desalination

2.3.2 Engineering Analysis and Investigation

DME_S2_2. The ability to formulate, analyze, and solve thermal engineering and desalination problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Compare size and rate of heat exchanger types
2. Analyze steam power components and the integrated cycle
3. Examine the effect of different parameters on plant performance
4. Examine the effect of various design parameters on the gas turbine performance
5. Compare the characteristics of the axial and centifugal compressors, and axial flow and radial flow turbines together with their applications
6. Examine various types of combustion systems, their methods of operation, types of fuel and the corresponding environmental impact
7. Analyze energy distribution, power and efficiencies of an internal combustion engine
8. Analyze the effect of engine parameters on engine performance
9. Solve basic vapor compression refrigeration cycle
10. Use psychometric charts to analyze basic air conditioning cycles
11. Perform cooling load for a building
12. Solve refrigeration cycle problems using computer programs
13. Examine the physical characteristics of boiling and condensation modes and working of cooling towers
14. Analyze different desalination processes: single and multi-effects submerged tube evaporators, multi-effects falling film evaporators, single and multi-effects vapor compression, single and multi-stage once-through, and multi-stage flash desalination processes

2.3.3 Engineering Design

DME_S2_3. The ability to design thermal systems, components, or processes while observing codes of practice, standards, economic, environmental, societal, ethical, health and safety constraints.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Design heat exchangers
2. Design water tube boiler components
3. Design a single turbine stage
4. Design condensers and cooling towers
5. Design centrifugal and axial flow compressors
6. Design axial flow turbines
7. Design evaporators
8. Design multi-stage flash distillation (MSF) units
9. Observe codes and standards in design

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Appendix: Revised Bloom's Taxonomy [11]

Categories	Cognitive Process	Sample Verbs Commonly used for Stating Specific Learning Outcomes
Remembering	Retrieve relevant knowledge from long-term memory Recognizing Recalling	Collect, Define, Describe, Examine, Identify, Label, List, Name, Quote, Show, Tabulate, Tell
Understanding	Construct meaning from instructional messages, including oral, written, and graphic communication Interpreting Exemplifying Classifying Summarizing Inferring Comparing Explaining	Associate, Contrast, Describe, Differentiate, Discuss, Distinguish, Estimate, Extend, Interpret, Predict, Summarize
Applying	Carry out or use a procedure in a given situation Executing Implementing	Apply, Calculate, Change, Classify, Complete, Demonstrate, Discover, Examine, Experiment, Illustrate, Modify, Relate, Show, Solve

Analyzing	Break material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose Differentiating Organizing Attributing	Analyze, Arrange, Classify, Compare, Connect, Divide, Explain, Infer, Order, Select, Separate
Evaluating	Make judgments based on criteria and standards Checking Critiquing	Assess, Compare, Conclude, Convince, Decide, Discriminate, Explain, Grade, Judge, Measure, Rank, Recommend, Select, Summarize, Support, Test
Creating	Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure Generating Planning Producing	Combine, Compose, Design, Formulate, Generalize, Integrate, Invent, Modify, Plan, Create, Prepare, Rearrange, Rewrite, Substitute

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