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

## (Industrial 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.

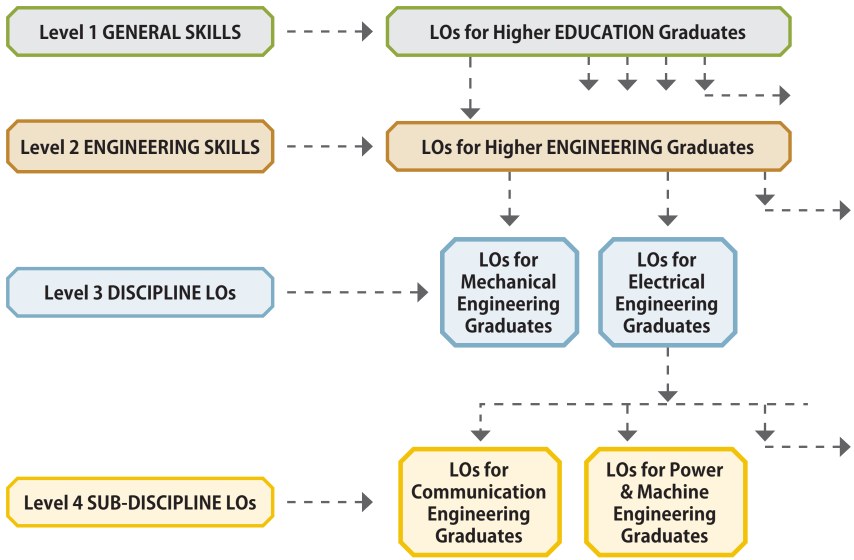


Fig. 1 Hierarchy levels of QIYAS Framework of Engineering Learning Outcomes

# 2. INDUSTRIAL ENGINEERING LEARNING OUTCOMES (IE)

## 2.1 Discipline Level Learning Outcomes

Industrial Engineering **(IE)** skills include the knowledge of the fundamentals of the four main areas of Industrial Engineering: manufacturing systems engineering, industrial operations systems engineering, logistics and human factors engineering and quality engineering. Industrial engineering graduates should be able to build on their acquired skills pertaining to basic and engineering sciences, engineering analysis, engineering design, investigation and practice skills, and consequently acquire industrial engineering discipline-level skills and demonstrate their knowledge and understanding of the basic concepts governing various industrial engineering sciences and the associated design and operating principles.

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

### 2.1.1 Engineering Sciences

**DIE1**. The ability to identify, define and model manufacturing and service systems by applying industrial engineering sciences and tools.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use the principles and elementary constructs of systems models including discrete-time and state system theories, and life-cycle performance
2. Define the principles of production management systems (planning, organizing, and control of production systems)
3. Recognize engineering materials properties and processing parameters
4. State the fundamentals of industrial economics
5. Apply the principles of reliability, failure distributions and reliability characteristics.

**DIE2**. The ability to combine technical knowledge and skills from industrial engineering and social sciences to evaluate and monitor system performance.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize the basics of industrial cost analysis and accounting
2. Use the basics of analysis of engineering economy
3. Define the basic concepts of quality and demonstrate an appreciation of the functions served by a quality management system
4. Apply the principles of Human-Machine Systems
5. Utilize the basic work measurement techniques

### 2.1.2 Engineering Analysis and Investigation

**DIE3**. The ability to analyze, solve, and implement efficient and effective solutions to realistic problems in the industrial systems by applying industrial engineering tools, contemporary knowledge and cutting-edge technologies.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. State and use the concepts of mathematical programming and optimization
2. Perform sensitivity analysis
3. Apply the principles of minimum spanning tree (MST), shortest path (SP) and maximum flow minimum cut problems (MFMCP)
4. Utilize the principles of Goal Programming
5. Use the fundamentals of Deterministic Dynamic Programming
6. Apply the fundamentals of Analytical Trees and Fault Tree Analysis

**DIE4**. The ability to carry out experiments, analyze and explain the results.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply the principles and the tools of experiments design
2. Use IT techniques to gather, record, analyze and present the data

### 2.1.3 Engineering Design

**DIE5**: The ability to design units, components, system or processes to meet preferred needs within sensible constraints such as ethical, manufacturability, environmental, political, social, economic, safety, quality, and sustainability.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize fundamentals of engineering materials
2. Design the production and inventory control systems
3. Apply the fundamentals of design of experiments and perform the response surface methodology
4. Design workplace
5. Recognize and obey the principles and applications of the time study by using stop-watch technique
6. Design automated handling and storage systems
7. Apply the safety regulations and standards, and plant safety applications

### 2.1.4 Engineering Practice

**DIE6**. The ability to understand professional conduct, ethical responsibility, codes, standards, tools, skills, and techniques that are necessary in both laboratory environment and engineering practice.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use the outputs from experiments at the industrial engineering laboratories
2. Recognize codes and standards in the industrial engineering profession
3. Communicate and work effectively and ethically as individuals and as team members
4. Demonstrate leadership roles in the profession and communities

## 2.2 Sub-discipline #1: Manufacturing Systems Engineering

This sub-discipline is concerned with the design of production processes and manufacturing systems. It includes many types of engineering sciences such as manufacturing technology, computer aided design and manufacture, manufacturing system design and operation.

### 2.2.1 Engineering Sciences:

**DIE_S1_1**. The ability to define and model manufacturing systems and its components by applying manufacturing engineering sciences and tools.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize the fundamentals of the manufacturing automation and strategies;
2. Form the manufacturing systems;
3. Apply the principles of cutting mechanisms, tool materials and geometry, cutting tools assembly techniques, and material removal operations;
4. Use the principles of labor cost and material cost analysis;
5. Apply the fundamentals of process control, control theory principles, digital control using programmable logic controller and computer.
6. Recognize the principles of facility design stages of industrial factory product

7. Apply the principles of computer aided process planning;
8. Use the principles of enterprise integration.

**DIE_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. Recognize the fundamentals of manufacturing systems.
2. Analyze manufacturing organizations including, group technology, job-shop, assembly lines manufacturing, inventory philosophies work environment, work simplification, and process flow analysis;
3. Recognize engineering materials and processing parameters that influence product quality, and production costs.
4. Apply the basic casting techniques and welding process.

**2.2.2 Engineering Analysis and Investigation:**

**DIE_S1_3**.The ability to analyze, solve, and implement efficient and effective solutions to realistic problems in the manufacturing systems by applying industrial engineering tools, contemporary knowledge and cutting-edge technologies.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. quantify the effects of cutting parameters on machining operations;
2. State, analyze and quantify the effects of machining variables on machine tool fundamentals and non-traditional machining;
3. Estimate the operation cost, product cost, and product pricing.
4. Recognize the principles of process and material handling analysis;
5. Apply the fundamentals of high volume manufacturing systems analysis;

6. Apply the basics of engineering analysis in manfuctature engineering decisions, project control, and forecasting; decisions tree analysis; production planning.

### 2.2.3 Engineering Design:

**DIE_S1_4**. The ability to analyze and design various components of manufacturing system, to meet preferred 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. Design and analysis cellular and flexible manufacturing systems (FMS);
2. Design the push and pull manufacturing systems
3. Apply the fundamentals of design of high volume manufacturing systems;
4. Apply the principles of the area allocation and space analysis; Flow analysis;
5. Apply the principles of plant layout;
6. Use computerized facility layout and allocations;
7. Apply the risk assessment techniques ;
8. Use the basics of process design selection;
9. Use the parameters of engineering materials and processing that influence design considerations;
10. Analyze the economic aspects of industrial production systems
11. Design and analysis of the components of lean manufacturing systems.

### 2.2.4 Engineering Practice:

**DIE_S1_5**. The ability to recognize and distinguish manufacturing system equipment in laboratory environment and practical engineering sites.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Analyze and perform industrial engineering experimental data and output information from experiments at the manufacturing engineering laborites (Metrology Lab, advanced manufacturing technology Lab., CAM lab, and reverse engineering lab.)

## 2.3 Sub-discipline #2: Industrial Operation and Logistics

This sub-discipline is concerned with industrial analysis. It includes many types of engineering sciences such as operation research, production planning and control, and manufacturing cost analysis.

### 2.3.1 Engineering Sciences:

**DIE_S2_1**. The ability to demonstrate knowledge and understand the basics of Industrial operation and logistics.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize the principles of production systems;
2. Identify and analyze the variables affecting the quality level of the product
3. Recognize the fundamentals of using different types of control charts to monitor the manufacturing processes.
4. Apply the reliability testing methodologies;
5. Apply the basics of modeling different industrial programs such as linear programs (LP) and graphical solutions;
6. Apply the principals of simplex methods;
7. Use the principles of production and assembly line balancing;
8. Apply the basics of nonlinear programming; Integer programming; Branch and bound methods; KKT conditions and quadratic programming; Single and multi

variable unconstrained optimization; Markov chains;

9. Use the fundamentals of different types of inventory models for single and multi-item systems.

### 2.3.2 Engineering Analysis and Investigation:

**DIE_S2_2**. The ability to analyze, solve and implement efficient and effective solutions to realistic problems in the Industrial operation systems by applying industrial engineering tools.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use data processing technology, databases and their applications
2. Apply the principles of industrial information and retrieval systems with special emphasis given to industrial operation systems;
3. Use computerized maintenance management systems (CMMS).
4. Analyze the output from a simulation model; Validation of the simulation model.
5. Apply the fundamentals of implementing prototype metrologies;

### 2.3.3 Engineering Design:

**DIE_S2_3**.The ability to carry out the design of industrial operation systems, and its elements, or a process to meet desired needs by using computer aided design tools.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply the fundamentals of geometric modeling and its approaches;
2. Apply the fundementals of geometric transformations;
3. Apply the fundementals of numerical control; finite element modelling; Numerical control programming; Group technology
4. Design flow lines for industrial systems;

5. Design production and inventory control systems;
6. Analyze large-scale decision problems by using linear decision models;
7. Design, perform, and evaluate supply chain systems.

**2.3.4 Engineering Practice:**

**DIE_S2_4**.The ability to select and use control of industrial operation systems

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Perform laboratory exercises illustrating the control of industrial operation processes including hazard function (advanced manufacturing technology lab.)

## 2.4 Sub-discipline #3: Human factors Engineering and Safety

This sub-discipline is concerned with design and analysis of work and its time, and safety. It includes many types of engineering sciences such as human factors analysis, time and motion study and safety engineering.

**2.4.1 Engineering Sciences:**

**DIE_S3_1**. The ability to demonstrate knowledge and understanding of the basics of human factors analysis, time and motion study and safety engineering.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply the analysis of work methods.
2. Use the fundamentals of study of time standards and work sampling.

### 2.4.2 Engineering Analysis and Investigation:

**DIE_S3_2**. The ability to analyze, solve and implement efficient and effective solutions to realistic problems in the areas of Human factors engineering and safety engineering by applying industrial engineering tools.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use industrial hazard avoidance concepts and techniques;
2. Recognize the fundamentals of ergonomics in work environment;
3. Apply the principles of measurement of physical work capacity;
4. Apply the principles of occupational safety and health;
5. Apply the fundamentals of workplace environmental;
6. Use thermal factors for evaluating system performance.

### 2.4.3 Engineering Design:

**DIE_S3_3**. The ability to carry out the design of industrial systems and its elements or process to meet preferred needs using Human factors and safety Industrial engineering tools and techniques.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Design different types of displays and controls
2. Apply the fundamentals of Human Capabilities;
3. Use the principles of health, safety procedures and programs
4. Apply the principles of basic work measurement techniques
5. Design Hand Tools and Devices according to human factors principles;
6. Design the components of workplace
7. Recognize the fundamentals of Physical Work and Manual Materials Handling and Speech Communications.

**2.4.4 Engineering Practice:**

**DIE_S3_4**. The ability to select, use control, evaluation and improvement of human-machine systems for objectives of the Industrial system.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply the principles of process control fundamentals.
2. Perform laboratory experiments illustrating the control of industrial operation processes including hazard function. (Human factors lab; Work study lab; Safety engineering lab.).

## 2.5 Sub-discipline #4:Quality Engineering

This sub-discipline is concerned with design and analysis of quality system that is necessary for different production organizations. It includes many types of sciences such as quality engineering, quality management and productivity.

**2.5.1 Engineering Sciences:**

**DIE_S4_1**. The ability to demonstrate knowledge and understanding of the basics of Quality engineering.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize the basic concepts of quality;
2. Recognize the principles of the functions served by a quality management system;
3. Apply the principles of productivity;
4. Use the principles of improving quality and its critical factors.
5. Use the principles of sampling inspection techniques.

**2.5.2 Engineering Analysis and Investigation:**

**DIE_S4_2**. The ability to analyze, solve and implement efficient and effective solutions to realistic problems in the areas of quality engineering by applying industrial engineering tools.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Analyze the principals of distributions and probability theories in the area of quality control;
2. Use computer software in quality area;
3. Recognize the principles of quality management systems (Kezien; ISO 9000; Balance Score Card (BSC); Total Quality Management (TQM));
4. Apply the principles of distribution theory and particular distributions of interest in quality engineering area;
5. Apply the principles of vendor sourcing and control tools.

**2.5.3 Engineering Design:**

**DIE_S4_3**. The ability to carry out the design of quality system and its elements, to meet desired needs using quality tools and techniques.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Design quality into products so as to satisfy both internal and external customer;
2. Deign and apply various control charts;
3. Design different sampling plans;
4. Analyze quality costs;
5. Apply the methods for establishing specifications and tolerances;
6. Use the principles of quality function deployment;

7. Use the principles of process capability;
8. Design quality control systems;
9. Apply reliability analysis;
10. Use the principles of hypothesis testing, two and multi factor factorial design to design better products and processes.

**2.5.4 Engineering Practice:**

**DIE_S4_4**. The ability to select, use control, evaluation, and improvement of Quality System.

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply the principles of process control fundamentals
2. Perform laboratory experiments to demonstrate the operation and control of quality system. (Metrology and quality engineering lab.)

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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<br>Recognizing<br>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<br>Interpreting<br>Exemplifying<br>Classifying<br>Summarizing<br>Inferring<br>Comparing<br>Explaining | Associate, Contrast, Describe, Differentiate, Discuss, Distinguish, Estimate, Extend, Interpret, Predict, Summarize |
| Applying | Carry out or use a procedure in a given situation<br>Executing<br>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<br>Differentiating<br>Organizing<br>Attributing | Analyze, Arrange, Classify, Compare, Connect, Divide, Explain, Infer, Order, Select, Separate |
| Evaluating | Make judgments based on criteria and standards<br>Checking<br>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<br>Generating<br>Planning<br>Producing | Combine, Compose, Design, Formulate, Generalize, Integrate, Invent, Modify, Plan, Create, Prepare, Rearrange, Rewrite, Substitute |

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+ 966 11 490 9090
+ 966 11 490 9077
faq@qiyas.org
P.O box 68566 Riyadh 11537
www.qiyas.sa
QiyasOnline