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

(Civil 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.

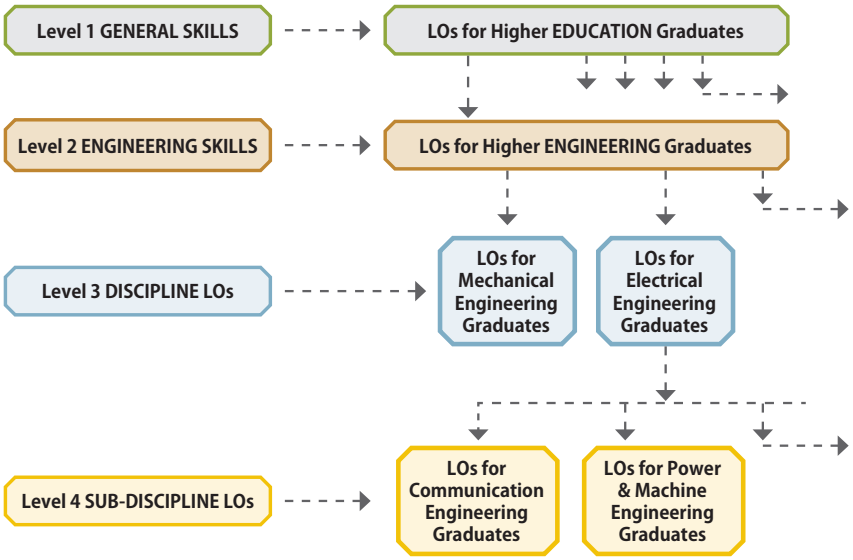

Fig. 1 Hierarchy levels of QIYAS Framework of Engineering Learning Outcomes

2. CIVIL ENGINEERING LEARNING OUTCOMES (CE)

2.1 Discipline Level Learning Outcomes

Civil Engineering **(CE)** skills include the understanding, knowledge and application of the fundamentals of various civil engineering principal areas, namely structural engineering area, geotechnical engineering area, water resources engineering area, environmental engineering area, transportation engineering area and construction management area. Civil engineering graduates should be able to build on their acquired skills pertaining to basic sciences and engineering fundamentals, engineering analysis and investigation, engineering design, as well as engineering practice, and consequently acquire civil engineering discipline-level skills. Civil engineering graduates should attain knowledge and understanding of general engineering skills and to apply principles of civil engineering to formulate, analyze, design and realize physical systems, components, or processes in various civil engineering principal areas.

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

2.1.1 Engineering Sciences

DCE1. The ability to apply the fundamental knowledge of basic and engineering sciences, including mathematics, physics, chemistry as well as the theoretical and analytical basis of generic civil engineering principal areas

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe the fundamentals of engineering mechanics (statics and dynamics), and fluid mechanics
2. Recognize the fundamental knowledge of material sciences and natural sciences (such as geology, ecology, or biology)
3. Describe the fundamentals of engineering drawing, surveying and spatial measurements
4. Apply knowledge of computers, measurements and controls in various civil engineering problems and processes

DCE2. The ability to demonstrate knowledge of the subject-specific fundamentals of civil engineering

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply knowledge in the structural analysis, construction engineering and behavior of construction materials
2. Demonstrate the basics of geotechnical and foundation engineering principals and related issues
3. Demonstrate the basics of transportation systems and related issues
4. Apply knowledge of environmental engineering, waste water and water resources engineering
5. Apply knowledge of construction planning, scheduling and cost estimations

2.1.2 Engineering Analysis and Investigation

DCE3. The ability to apply technical engineering knowledge as appropriate to civil engineering applications

Learning Outcomes

Graduates who possess this ability should be able to:

1. Analyze and model structural components or systems or processes
2. Conduct tests in construction materials, soils and pavement materials
3. Analyze, interpret and assess water and wastewater parameters and related processes
4. Analyze and synthesize different results from experiments
5. Utilize and combine the obtained results with other factors including economical, social, safety and environmental aspects to reach alternative and optimized solutions
6. Address construction engineering and management problems

2.1.3 Engineering Design

DCE4. The ability to demonstrate knowledge of the subject-specific applied civil engineering areas and design (structures, foundations, water supply systems and sewer networks, transportation systems etc.) with a good knowledge of associated constraints including safety, quality, schedule and cost estimates and measures.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Design buildings and bridges and other civil engineering systems
2. Design dams, flood protection and water retaining structures
3. Design water supply systems, sewer networks, water distribution systems and drainage networks
4. Design transportation systems including roads, runway and pavements
5. Use relevant computer programs and software to design and model the systems under challenges of real-life constraints
6. Integrate different civil engineering disciplines in capstone design projects

2.1.4 Engineering Practice

DCE5. The ability to demonstrate knowledge of different project elements and issues related to construction of common civil engineering works. Follow the latest developments in civil engineering design, practices and codes.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Compare the different stages involved in project construction, planning, management and bidding processes
2. Comply with appropriate standards, specifications and codes of practices in design projects
3. Implement issues related to project design such as health, safety, cost analysis and environmental issues
4. Appraise the updates in the design codes and standards
5. Recognize updated versions of software, new developments in engineering tools, materials and construction methods and systems

DCE6. The ability to understand the importance of professional and ethical responsibilities of civil engineers, and the awareness of the codes of conduct and other sources of guidance

Learning Outcomes

Graduates who possess this ability should be able to:

1. Recognize the professional and ethical responsibilities of each of the owner, contactor and consultant
2. Identify and report cases of misconducting, mishandling or mismanaging in civil engineering projects
3. Establish team work and co-operation with professionals of the same and other professions

2.2 Sub-discipline #1: Structural Engineering

Structural engineering skills include the knowledge of analyzes and design of structural engineering components and processes. Structural engineering graduates must be able to build on their acquired knowledge and skills pertaining to basic discipline-level civil engineering leanings in order to understand, synthesize, analyze and design specialized structural devices and systems.

2.2.1 Engineering Sciences

DCE_S1_1. The ability to understand and demonstrate knowledge of fundamentals related to structural engineering.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply equilibrium equations to analyze truss, beam, and frame structures
2. Describe stress and strain, deformation, multiaxial stresses and buckling concepts

2.2.2 Engineering Analysis and Investigation

DCE_S1_2. The ability to understand, formulate, analyze, solve and implement effective and efficient solutions to structural engineering problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Compute the internal forces for beams, frames and trusses for determinate structures
2. Apply numerical methods for analysis of displacements and slopes for beams frames and trusses
3. Use different methods for analysis of indeterminate structures
4. Investigate properties of concrete and other materials
5. Recognize new developments in materials, techniques and design specifications
6. Comply with code requirements of durability for the design and construction of concrete structures

2.2.3 Engineering Design

DCE_S1_3. The ability to analyze and design various components and processes related

to the structural engineering within associated constraints including safety, quality, economic, environmental and social.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Recognize the importance of building codes and their role in the design process
2. Design beams, columns, slabs and other components of building and bridge systems and processes
3. Compute design loads within code constraints of safety, serviceability and economy
4. Check deflections in reinforced concrete beams, slenderness and stability of columns under code provisions

2.3 Sub-discipline #2: Geotechnical Engineering

2.3.1 Engineering Sciences

DCE_S2_1. The ability to understand and demonstrate knowledge of fundamentals related to geotechnical engineering

Learning Outcomes

Graduates who possess this ability should be able to:

1. Recognize the basics of engineering geology
2. Recognize the importance of weathering and erosion phenomena and the different types of rocks and their origin
3. Recognize the basic properties of soils and rocks and their expected physical behavior

2.3.2 Engineering Analysis and Investigation

DCE_S2_2. The ability to understand, formulate, analyze, solve and implement effective and efficient solutions to geotechnical engineering problems

Learning Outcomes

Graduates who possess this ability should be able to:

1. Conduct laboratory experiments and field tests to determine the physical and engineering properties of soils and rocks
2. Conduct site investigations
3. Conduct settlement analysis, lateral earth pressure and slope stability analysis
4. Assess the bearing capacity and behavior of soils and rocks under loads
5. Analyze stability of natural or manmade soil and rock slopes
6. Evaluate the behavior of problematic soil

2.3.3 Engineering Design

DCE_S2_3. The ability to analyze and design various components and processes related to the geotechnical engineering within associated constraints including safety, quality, economic, environmental and social

Learning Outcomes

Graduates who possess this ability should be able to:

1. Select the appropriate types of foundations and retaining structures according to the site and structure characteristics
2. Design various types of foundations and retaining structures

2.4 Sub-discipline #3: Water Resources Engineering

2.4.1 Engineering Sciences

DCE_S3_1. The ability to understand and demonstrate knowledge of fundamentals related to water resources engineering

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe fluid properties, fluid dynamics and the concepts of conservation of momentum and energy
2. Compare pressure values and pressure force on surfaces
3. Assess stability of submerged and floating bodies
4. Describe hydrological cycle, surface and groundwater hydrology

2.4.2 Engineering Analysis and Investigation

DCE_S3_2. The ability to understand, formulate, analyze, solve and implement effective and efficient solutions to water resources engineering problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Use momentum conservation concept to evaluate forces of moving bodies
2. Apply energy conservation concept of moving fluids
3. Analyze flow in pipes networks using different formulae and methods
4. Analyze, evaluate and select pumps and pump stations
5. Analyze and compute flow in open channels
6. Model the hydrological processes

7. Apply the basic principles of water resources planning with different considerations in planning: economic, social, legislative and environmental
8. Describe methods of groundwater movement and hydraulics of wells
9. Analyze the results of lab experiments on different flow phenomena

2.4.3 Engineering Design

DCE_S3_3. The ability to analyze and design various components and processes related to the water resources engineering within associated constraints including safety, quality, economic, environmental and social.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Design of rigid-boundary channels
2. Recognize the importance of hydrology for the planning, design and operation of water resource systems
3. Design drainage networks and hydraulic structures

2.5 Sub-discipline #4: Transportation Engineering

2.5.1 Engineering Sciences

DCE_S4_1. The ability to understand and demonstrate knowledge of fundamentals related to transportation engineering.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe basic transportation systems components and concepts

2. Outline traffic flow characteristics, including capacity, speed and safety considerations
3. Predict travel demand and traffic forecasting

2.5.2 Engineering Analysis and Investigation

DCE_S4_2. The ability to understand, formulate, analyze, solve and implement effective and efficient solutions to transportation engineering problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Identify basic procedures for highway capacity and level of service
2. Assess highway transportation costs, methods of economic analysis, and environmental impact of highways
3. Conduct testing of pavement materials: soil, aggregates and asphalt
4. Analyze traffic accident data

2.5.3 Engineering Design

DCE_S4_3. The ability to analyze and design various components and processes related to the transportation engineering within associated constraints including safety, quality, economic, environmental and social.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe basic procedures for traffic signal design
2. Compute stresses in flexible pavement, traffic loads

3. Design highway geometric elements, intersections and interchanges
4. Design pavement structures, bituminous mixes and flexible highway pavement
5. Select appropriate traffic control device and design intersection signalization

2.6 Sub-discipline #5: Environmental Engineering

2.6.1 Engineering Sciences

DCE_S5_1. The ability to understand and demonstrate knowledge of fundamentals related to environmental engineering.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe the nature of environmental pollution and human health
2. Identify sources of pollutants and their environmental pathways
3. Compare water supply and drainage systems, wastewater reclamation, recycling and reuse
4. Compare the types of industrial environmental pollution, types of pollutants, limits and the different technologies for pollution control

2.6.2 Engineering Analysis and Investigation

DCE_S5_2. The ability to understand, formulate, analyze, solve and implement effective and efficient solutions to environmental engineering problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Measure different parameters of water and wastewater

2. Conduct laboratory experiments for water and wastewater processing means
3. Describe procedures for control and management of environmental pollution
4. Analyze procedures required for water supply and drainage systems

2.6.3 Engineering Design

DCE_S5_3. The ability to analyze and design various components and processes related to the environmental engineering within associated constraints including safety, quality, economic, environmental and social.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe requirements for construction and maintenance of water and sewerage systems
2. Design water, wastewater treatment facilities and networks systems
3. Select treatment technologies for reclaiming and reusing wastewater
4. Apply procedures and specifications for water supply and drainage systems

2.7 Sub-discipline #6: Construction Management and Engineering

2.7.1 Engineering Science

DCE_S6_1. The ability to understand and demonstrate knowledge of fundamentals related to construction management.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Outline the management principles and the functions of project management

2. Describe fundamentals of engineering economy, construction cost estimates
3. Assess construction contracts, bidding and contract process
4. Compare equipment and labor productivity

2.7.2 Engineering Analysis and Investigation

DCE_S6_2. The ability to understand, formulate, analyze, solve and implement effective and efficient solutions to construction management problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Select appropriate construction method and type of equipment
2. Identify the inherent risks of contract conditions
3. Solve problems related to resource allocation, resource leveling
4. Compare the effect of work changes and delays of a project
5. Identify the causes of deviations in time and cost control, disputes and claims

2.7.3 Engineering Design

DCE_S6_3. The ability to analyze and design various components and processes related to the construction management within associated constraints including safety, quality, economic, environmental and social.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Design concrete formwork for slab, beam, column, and footings
2. Establish bidding procedures according to the selected project delivery method

3. Develop the framework for tenders
4. Review and formulate contract conditions

2.7.4 Engineering practice

DCE_S6_4. The ability to understand and demonstrate the elements of civil engineering works of a construction project.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Develop a complete time plan and project schedule for a project
2. Apply chart, precedence diagramming method, and time-scaled network time planning techniques
3. Monitor engineering projects for purpose of time and cost control
4. Forecast the cash-in and cash-out of the engineering project
5. Estimate the cost of work items, operation and maintenance of equipment
6. Compare the tender price and prepare the tender
7. Identify the rights and obligations of concerned parties
8. Resolve conflicts between contract drawings and specification
9. Conduct economic feasibility study of the project and decision-making on real world projects.

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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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