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

(Chemical Engineering)

December 2013

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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.

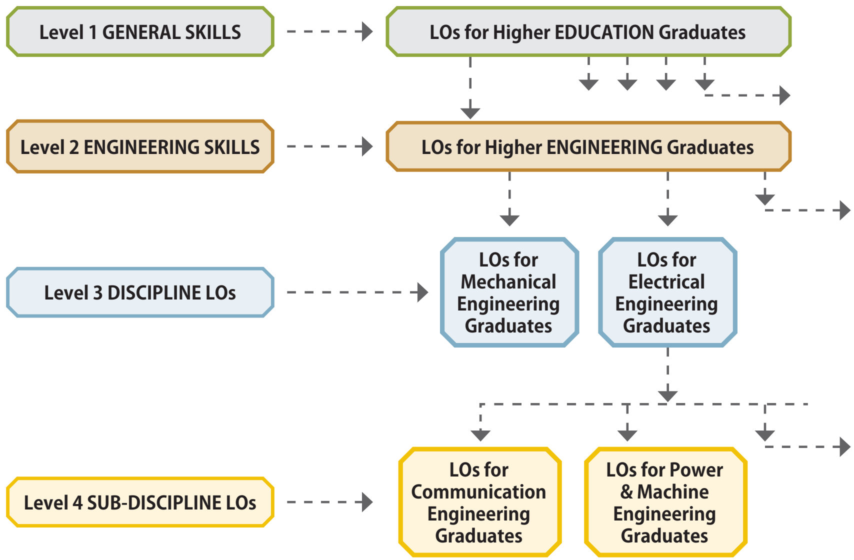

Fig. 1 Hierarchy levels of QIYAS Framework of Engineering Learning Outcomes

2. CHEMICAL ENGINEERING LEARNING OUTCOMES (CHE)

2.1 Discipline Level Learning Outcomes

Chemical Engineering (**ChE**) skills include the knowledge of basic sciences, foundation chemistry, general engineering fundamentals, and physical and chemical processes. Chemical Engineers apply, in a well-integrated manner, these areas of knowledge as well as their acquired soft skills for the analysis, design and ultimately operation and control of chemical plants while maintaining and preserving codes of practice, ethics, safety, health, economics and environment.

In addition to learning levels for the discipline, learning outcomes for five sub-disciplines are formulated. These include: (1) Petrochemicals and Petroleum Refining, (2) Desalination and Water Treatment, (3) Materials Science and Engineering, (4) Biochemical Engineering and (5) Chemical Industries.

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

2.1.1 Engineering Sciences and Foundation Chemistry

DChE1. The ability to demonstrate knowledge in foundation chemistry and fundamentals of chemical engineering

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe and apply the basics of inorganic and organic chemistry including: normality, molarity and molality; titration calculations; chemical reaction equations; paraffins, olefins, aromatics, alcohol, ethers, phenols, aldehydes, … etc.
2. State and use the concepts of units and dimensions; major process variables; psychrometric charts while performing basic material and energy balances

3. State the first and second law of thermodynamics and their implications while utilizing the volumetric properties of pure and mixed fluids.
4. Discuss the various properties of engineering materials; the atomic and crystalline structures of materials and the phase diagram of solid materials and be able to identify causes of materials failure and imperfections.

DChE2. The ability to demonstrate knowledge of physical processes encountered in chemical engineering practice including the various transfer and separation process.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe the fundamentals, physical meaning and equation governing these processes; explain fluid statics and dynamics and recognize the differences between flow through annulus, submerged bodies and porous media.
2. Define and distinguish the basics of physical transfer processes including heat and mass and the factors that affect transfer and diffusion processes such as fouling, scaling and mixing.
3. Apply the fundamentals of stage operations using phase diagrams and phase equilibrium and observing the main factors that affect them.

DChE3. The ability to demonstrate knowledge of chemical processes encountered in chemical engineering practice and the implications of reaction kinetics on them.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Use reaction stoichiometry and rate equations for irreversible and reversible reaction for both single and multiple reactions.
2. Relate the concepts of conversion, selectivity and yield.

DChE4. The ability to demonstrate basic knowledge of control systems used in chemical plants.

1. Recognize the process control structure and the concepts of set points, disturbances, controlled, manipulated variables and transfer functions.

2.1.2 Engineering Analysis and Investigation

DChE5. The ability to identify, formulate, analyze and solve common chemical engineering problems including physical and chemical processes or units.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply basic material and energy balances to analyze and solve problems for a unit, process or an entire flow sheet using sequential and/or process solutions by performing hand-calculations or using suitable computer simulation packages and softwares.
2. Identify and utilize the limitations imposed by thermodynamics on processes and thus choose and apply the proper equations of state including proper analysis of phase and chemical equilibria while examining the performance of power cycles.
3. Quantify the implications and differences in flow regimes and quantify the effects of elbows, constrictions and pipe size on power requirements of pumps. Utilize the properties of materials to select a suitable material for constructing pipes based on flowing fluid properties.
4. Calculate heat and mass transfer coefficients and the factors that affect them and estimate the properties and role of insulating materials on heat transfer and perform steady state analysis related to different modes of heat transfer.
5. Analyze stage-wise and continuous gas-liquid separation processes by applying graphical and analytical methods for stages determination for absorbers and distillation columns .
6. Appreciate the implications of changes in temperature, pressure and volume

on ideal reactor design by performing material and energy balances using rate expressions and determining reaction kinetics from experimental data.

7. Devise a proper control structure, PID controllers and analyze the performance and stability of systems.
8. Apply the basics of economic analysis and engineering economy concepts such as profit, depreciation, profitability, cash flow, present value and alternative investment to recognize the vital importance of economic analysis in plant design.

2.1.3 Engineering Design

DChE6. The ability to design units, components and plants to meet specific needs while observing technical, environmental, economical, societal, ethical and safety constraints.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply the basic principles of chemical engineering while observing limitations imposed by thermodynamics on units and their designs.
2. Appreciate the impact of the flowing material, flow type and material of construction on power requirements and the design of piping systems and pumps.
3. Use proper energy equations, codes and standards to supply energy requirements of the plant using equipment, such as heat exchangers and evaporators giving due consideration to the effect of phase on the design.
4. Apply the basics of mass transfer operations in the design of units such as absorption, distillation columns and liquid-liquid extraction units.
5. Apply the knowledge of basic material and energy balances and reaction kinetics in the design of ideal reactors (CSTR and PFR).

DChE7. The ability to utilize experimental data, softwares, empirical equations and rules of thumb in the design of chemical engineering units.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Interpret experimental data for the benefit of the design.
2. Use empirical equations and rules of thumbs in designing chemical engineering units.

2.1.4 Engineering Practice

DChE8. The chemical engineer must demonstrate understanding of the ethics of the profession, codes and standards in practice, safety, health, control, HAZOP analysis, costing, management and sustainability as well as contemporary issues and recent advances, innovations and modern developments in chemical engineering.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Use codes and standards in the chemical engineering profession.
2. Recognize the implications of professional responsibility regarding the design, operation and control of chemical processes as well as adherence to liability, accountability and codes of ethics in practice.
3. Recognize the development of new chemical processes, new analysis techniques and new software in the chemical engineering field.
4. Demonstrate sensitivity to preserving clean environment on issues related to waste disposal.

2.2 Sub-discipline #1: Petrochemicals and Petroleum Refining

Petroleum refining and petrochemicals are important industries. Special courses (e.g., petroleum refining, natural gas processing, heterogeneous reactors) in chemical engineering curricula provide the basic knowledge required for sub-specialization in this field.

2.2.1 Engineering Analysis

DChE_S1_1: The ability to understand, formulate, analyze and solve problems related to the petrochemicals and petroleum field.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Characterize, differentiate and evaluate crude oil.
2. Explain various oil refining techniques.
3. Analyze and apply physical separation methods in oil industry.
4. Analyze chemical conversion and treating techniques.
5. Perform product analysis and testing.
6. Analyze constituents of natural gas, transportation and storage.
7. Analyze and use different processes for gas treatment.
8. Appreciate and quantify the role of catalysts (porous or nonporous) on reaction kinetics.
9. State, analyze and quantify adsorption phenomena and their implications.
10. State, analyze and quantify diffusional effects on catalytic performance.
11. Analyze and quantify catalyst deactivation.
12. Recognize the differences between multiphase reactors.
13. Analyze and apply environmental considerations in oil and gas industry.

2.2.2 Engineering Design

DChE_S1_2. The ability to analyze and design various units in the petrochemicals and petroleum field while observing codes of practice, standards, economic, environmental, ethical, societal, health and safety constraints.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Design refinery units.
2. Design units for natural gas treatment.
3. Perform cost analysis and seek design alternatives.
4. Design heterogeneous reactors.
5. Recognize the importance of economic, environmental, safety, health and ethical considerations in design.
6. Apply environmental, safety, health and ethical constraints in design.
7. Use codes and standards in material selection.

2.3 Sub-discipline #2: Desalination and Water Treatment

Desalination of sea water and recycling of wastewater are two main means of providing and conserving water. Sub-specialization in this field requires knowledge of the major principles, methods and applications of water desalination and wastewater treatment.

2.3.1 Engineering Analysis

DChE_S2_1. The ability to understand, formulate, analyze and solve problems related to water desalination and wastewater treatment field.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Characterize sea and brackish water.
2. Analyze and discriminate the different types of desalination technology.
3. Analyze the use of solar and nuclear energy in desalination.
4. Identify and analyze sources of water contaminants.
5. Discuss and apply various physical, chemical and biological wastewater treatment techniques.
6. Describe the various reactions involved in water treatment.
7. Select and use different disinfection techniques in water.

2.3.2 Engineering Design

DChE_S2_2. The ability to analyze and design various units in the desalination and water treatment field 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 multistage flash distillation (MSF) units.
2. Design reverse osmosis (RO) and membrane units.
3. Recognize and apply the factors that affect the design of desalination facilities.
4. Design biological wastewater treatment facilities.
5. Design attached growth facilities.
6. Recognize the importance of economic, environmental, safety, health and ethical considerations in design.
7. Use codes and standards in material selection.

2.4 Sub-discipline #3: Materials Science and Engineering

Materials science and engineering are of utmost importance for practicing engineers. Sub-specialization in this field requires knowledge of materials structures, factors that lead to material failure, corrosion, extractive metallurgy and electrochemistry.

2.4.1 Engineering Analysis

DChE_S3_1. The ability to understand, formulate, analyze and solve problems related to materials science and engineering field.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Explain the technical and economic importance of corrosion.
2. Classify corrosion processes.
3. Identify and analyze causes and consequences of corrosion.
4. Monitor, test and analyze corrosion.
5. Control and prevent corrosion.
6. Recognize the fundamentals of extractive metallurgy.
7. Apply various processes (calcinations, flotation, roasting, pyro-, hydro- and electro-metallurgy).
8. Define means of metal recycling.
9. Recognize the fundamentals of electrochemical engineering.
10. Analyze electrochemical cells.
11. Analyze and apply the thermodynamics and kinetics of electrochemical systems
12. Perform economic analysis of electrochemical processes.

2.4.2 Engineering Design

DChE_S3_2. The ability to analyze and design various units in the materials science and engineering field 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 extractive metallurgy units.
2. Design a corrosion control system.
3. Design various electrochemical systems.
4. Recognize the importance of economic, environmental, safety, health and ethical considerations in design.
5. Use codes and standards in material selection.

2.5 Sub-discipline #4: Biochemical Engineering

Biotechnology is currently one of the most important fields. It requires knowledge of some basic bio-related science courses to compliment the chemical engineering knowledge.

2.5.1 Engineering Analysis

DChE_S4_1. The ability to understand, formulate, analyze and solve problems related to biochemical engineering field.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Recognize, define and describe the fundamentals of biology, biochemistry and molecular biology.
2. Describe and utilize the main differences between enzyme and cell kinetics.
3. Apply the chemical engineering principles to analyze biochemical processes.
4. Recognize and analyze the main units applied in down-stream processing.
5. Apply the fundamentals of biochemical operations in waste water treatment .
6. Analyze and apply the fundamental chemical/biochemical engineering knowledge in the area of environmental biotechnology.
7. Estimate the role of microorganisms in processes.
8. Explain biofilm formation.
9. Discuss bio-corrosion.
10. Quantify mineral leaching.
11. Analyze the use of renewable resources.
12. Manipulate environmental conditions to enhance or retard a given process.

2.5.2 Engineering Design

DChE_S4_2. The ability to analyze and design various units in the biochemical engineering field 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 fermenters.
2. Apply scale-up techniques to bioreactors.
3. Design suspended growth and attached growth bioreactors.
4. Recognize the impact of biotechnology on society and environment.
5. Obey all codes, rules and regulations in biotechnology.
6. Design under economic, operational, legal, ethical, safety and health constraints.

2.6. Sub-discipline #5: Chemical Industries

Chemical industries are versatile. They could be considered as industries based on inorganic materials, such as cement, glass…. etc.

2.6.1 Engineering Analysis

DChE_S5_1. The ability to understand, formulate, analyze and solve problems related to chemical industries field.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Characterize and use the different types and sources of fuels.
2. Optimize energy consumption in chemical industries.
3. Utilize renewable energy resources.
4. Analyze the impact of energy on the environment.
5. Analyze and use the operations involved in the production of Building and Cementing Materials.
6. Analyze and classify cements.
7. Analyze and use bricks, glasses and insulating materials.

2.6.2 Engineering Design

DChE_S5_2. The ability to analyze and design various units in the chemical industries field 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 kilns and furnaces.
2. Apply codes and standards in design.
3. Design under economic, legal, environmental, operational, ethical, safety and health constraints.

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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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