

National Center for Assessment in Higher Education (QIYAS)

Framework for Assessing Learning Outcomes in Engineering

(General Skills and General 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 Zealand, 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.

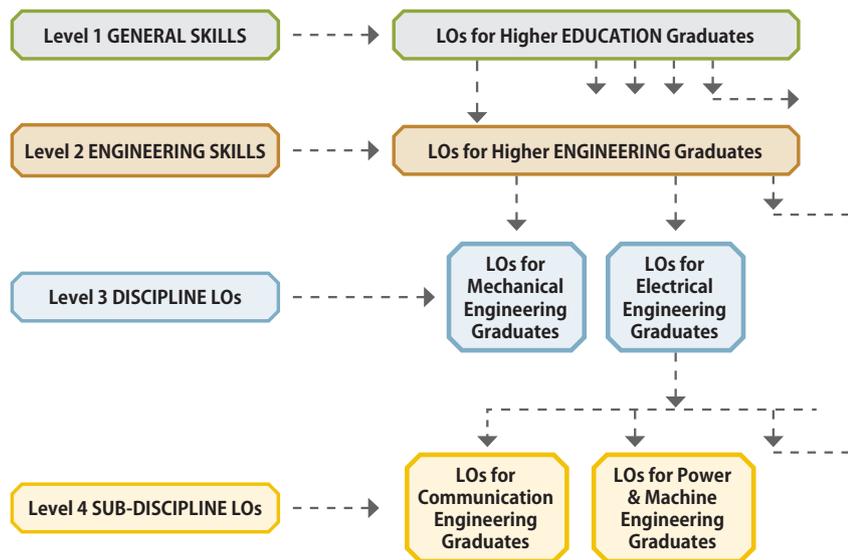


Fig. 1 Hierarchy levels of QIYAS Framework of Engineering Learning Outcomes

2. GENERAL SKILLS (GS)

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. They cover six types of skills, namely: 1) Communication skills, 2) Numeracy and calculation skills, 3) Computer literacy skills, 4) Interpersonal skills, 5) Problem solving skills, and 6) Learning and performance improvement skills. More specifically, they can be elaborated as:

2.1 Communication Skills

The ability to communicate effectively with others, in both native and English languages, organize information and data in a clear and concise manner, master oral presentation of information, accommodate different audiences, and formulate responses to written requests. The graduates are expected to:

1. Exhibit fluency in both Arabic and English languages
2. Communicate formally and informally as practiced in the industry
3. Write reports in a correct, clear and coherent way
4. Use automation and digital tools for effective and efficient communication and teamwork correspondence
5. Give clear, effective and engaging oral presentations
6. Adapt customized style for different audiences (e.g. managers, peers, customers and clients, etc.)
7. Develop flexibility to communicate and interact in different roles within the organization
8. Engage in productive and respectful debates and negotiations
9. Recognize and adapt to different communication cultures and norms of different countries, organizations and individuals

2.2 Numeracy and Calculation Skills

The ability to perform basic numeracy and calculation operations, understand and use basic mathematical methods, analyze and interpret numerical data, explain findings via presentation to various audiences, organize and assemble numerical data and non-numerical information. The graduates are expected to:

1. Recognize numeric scales and make measurements and observations using different units
2. Read and comprehend scale drawings, graphical displays, charts, and tabular data
3. Draw graphs from data or algebraic functions using common computer aided packages
4. Organize, sort and classify data using appropriate software packages
5. Perform calculations and attain required accuracy levels using various mathematical, numerical and graphical display methods
6. Deduce relationships between variables using numerical, graphical and algebraic methods

2.3 Computer Literacy Skills

The ability to master basic computer hardware and software functions, retrieve information through online computer searches, use word-processing and spreadsheets, perform data-logging and storage, and communicate via the Internet (email, etc.). The graduates are expected to:

1. Understand the basic operations of the computer
2. Use Internet for retrieving information through online searches
3. Enter and process information using spreadsheets
4. Create, edit and manipulate graphic files
5. Prepare, enter and manipulate data in databases
6. Use email to communicate with others
7. Evaluate the strengths of different computer tools and packages

2.4 Interpersonal Skills

The ability to express personal opinions clearly, collaborate with others (both individually and within team environment), understand group dynamics and dialogues, honor ethical values, and be conscious of general safety and environmental issues. The graduates are expected to:

1. Work cooperatively and productively with other team members to deliver the required outcomes
2. Gain trust of coworkers as an honest advisor and reliable assistant
3. Take a responsibility for developing and achieving group goals
4. Actively seek, identify and create effective contacts with others, and maintain those contacts for mutual benefits
5. Exhibit enthusiasm and energy by being constructive and goal-oriented as well as maintaining a positive attitude
6. Seek opinions and exchange feedback with other team members
7. Strive for ways to resolve conflicts and deal with difficulties while being sensitive to other people's opinions
8. Recognize and honor ethical values and sensitivity to surrounding cultural traditions, including Islamic values and Saudi Arabia heritage.

2.5 Problem Solving Skills

The ability to master problem solving tasks, identify, define and formulate problems, process qualitative and quantitative information, perform analytical reasoning and logical interpretation of results, derive recommendations and course of actions, and assess work success. The graduates are expected to:

1. Diagnose a problem by the clarification of its nature through the formulation of inquiries as well as the assembling and the organization of relevant information and data

2. Define the desired objectives and decide on resources to be allocated to solve the problem
3. Manage the solution of a problem by breaking it down into smaller - more manageable - parts
4. Generate and use variety of ways to tackle problems and identify creative and credible options that are likely to succeed
5. Provide an implementation plan for the problem solution
6. Monitor and critically employ problem solving skills including discussion with - feedback from - others
7. Examine the results and assess the problem-solving process and procedure, learn from experience and avoid reoccurrence of similar situations in future

2.6 Learning and Performance Improvement Skills

The ability to explore personal strengths and weaknesses, identify learning opportunities, exhibit critical analytical thinking, learn how to learn, develop special learning skills (such as speed-reading), and strive for life-long learning. The graduates are expected to:

1. Explore personal strengths and weaknesses
2. Set goals, targets and ways for improvement
3. Develop specialist learning skills
4. Get support and feedback from others
5. Review working environment
6. Identify ways for further improving learning and performance
7. Use iterative and critical thinking as well as the notion of inquiry to analyze situations systematically and generate pertinent solutions

3. ENGINEERING SKILLS

It is generally accepted and adopted that an Engineer must possess the understanding and the knowledge in, 1) basic sciences and engineering fundamentals, 2) engineering analysis and investigation, 3) engineering design and 4) engineering practice at the time of his graduation to practice engineering. Brief and summarized description of these skills is as follows:

3.1 Basic Sciences (BS) and Engineering Fundamentals (EF)

Basic Sciences and Engineering Fundamentals include the necessary knowledge required to understand and apply basic sciences (mathematics, physics, chemistry and statistics) and engineering fundamentals. Graduates from various disciplines of Engineering must be able to demonstrate their understanding and knowledge of their respective engineering fields as well as to work in the wider context of engineering profession.

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

BS1. The ability to apply university level mathematical skills to analyze and solve engineering problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply the principles and laws of linear algebra
2. Apply the major principles of differential and integral calculus
3. Recognize differential equations
4. Apply basic numerical techniques

5. Apply graphical presentation
6. Apply the basic principles and concepts of probability and statistics

BS2. The ability to utilize knowledge of chemistry and physics to solve engineering problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply the principles of physical equilibrium
2. Apply Newton's laws
3. Apply momentum conservation laws
4. Apply energy conservation laws
5. Use the concepts of friction
6. Recognize the effects of friction
7. Recognize thermal effects
8. Apply the laws of statics and dynamics
9. Apply the laws of electricity and magnetism
10. Complete and balance chemical reaction equations
11. Apply the principles of chemical equilibrium
12. Recognize the basic concepts of atomic structure

EF1. The ability to apply knowledge of engineering fundamentals and information technology. This ability encompasses, also, the integration of knowledge from other engineering disciplines with knowledge from the graduate's engineering discipline.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply the basics of thermodynamics
2. Apply the basics of fluid mechanics
3. Apply the basics of materials science
4. Recognize materials properties, characterization methods and processes
5. Perform appropriate procedures to identify properties/attributes of materials
6. Select appropriate materials based on functional and performance specifications
7. Produce engineering drawing
8. Apply appropriate basic scientific principles and techniques in engineering applications
9. Use appropriate assumptions for engineering applications
10. Implement appropriate computing techniques and information technology for engineering applications.
11. Recognize the basics of other engineering disciplines
12. Integrate various disciplines' knowledge to solve engineering problems
13. Recognize major technology changes within and outside the discipline.

3.2 Engineering Analysis and Investigation (AI)

Engineering Analysis and Investigation include knowledge and understanding of procedures and experiments required to analyze and solve engineering problems. This includes literature searches, problem identification and specification, seeking alternative solutions and selecting and implementing the optimum solution. This ability encompasses experimental procedures and design, data interpretation. It includes also mathematical analysis, computer modeling and simulation. The graduate must be able to recognize environmental, societal, safety, commercial and health constraints. Graduates are also expected to have appropriate investigative techniques.

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

AI1. The ability to identify, formulate, assess, and solve complex engineering problems in a creative and innovative manner. Graduates are also expected to use appropriate analytical, modeling, and simulation techniques

Learning Outcomes

Graduates who possess this ability should be able to:

1. Apply engineering principles
2. Apply engineering methods
3. Assess the nature of the problem based on engineering principles
4. Formulate engineering processes and analyze key engineering procedures
5. Propose a range of solutions to an engineering problem
6. Establish uncertainties and error bounds
7. Solve engineering problems within specified requirements
8. Implement creativity and innovations in engineering solutions
9. Identify the performance of systems and components
10. Classify and describe the method to be employed.
11. Identify uncertainties and limitations of methods
12. Apply appropriate analytical methods and numerical techniques within specified limitations.

AI2. The ability to (a) design and perform relevant experiments, (b) analyze and interpret experimental data considering uncertainties and (c) draw valid conclusions.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Establish relevant design criteria for the experiment

2. State the objectives to be achieved from the experiment
3. Use appropriate tools
4. Recognize uncertainties and limitations of the experiment
5. Plan for the experiment
6. Manage the experiment
7. Conduct appropriate experiment to achieve set objectives within safety standards
8. Apply modern data acquisition hardware
9. Present, tabulate and analyze experimental data
10. Plot necessary graphs and charts using IT tools
11. Interpret the results of the experiment within specified uncertainties
12. Recognize the limitations of data obtained from physical measurements
13. Draw valid and realistic conclusions
14. Use appropriate analytical, scientific and engineering tools to synthesize the data

AI3. The ability to (a) perform searches of various sources of information and (b) evaluate the consistency, validity, and relevance of data.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Describe the relevance of literature.
2. Identify sources of information
3. Use modern tools to conduct relevant searches
4. Assess the nature of the data
5. Explain the logical methodologies and tools
6. Recognize the limitations and uncertainties of data
7. Establish relevant validation criteria

3.3 Engineering Design (ED)

In engineering design, components of a system, whole system or a product are devised to meet specific needs. It requires creativity, formulation of design specifications, use of contemporary design theories, inventing solutions to open-ended problems, and evaluation of alternative designs. Economic, environmental, cultural, health, societal, legal considerations must all be observed in design as well as co-operation with engineers and non-engineers.

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

ED1. The ability to (a) create, conceive, develop, and evaluate design solutions to meet defined and specified requirements and (b) apply design methodologies to establish innovative solutions to open-ended engineering problems.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Convert need's statement to design objectives
2. Sub-divide a complex problem into smaller problems
3. Transform design objectives into physical realities
4. Establish criteria for design success
5. Prioritize tasks appropriately
6. Create realizable timetables and milestones
7. Manage time and resources
8. Develop strategies to monitor progress
9. Develop mathematical model of a particular engineering problem
10. Apply modeling techniques to facilitate design decisions
11. Generate design alternatives through creative techniques and evaluate design tradeoffs

12. Distinguish feasible solutions
13. Use evaluation criteria and contemporary knowledge to objectively select the optimum design from alternative designs
14. Use codes and related standards.
15. Build prototypes (hardware, software or both) to test the proposed design

ED2. The ability to design while observing non-technical requirements such as (a) political, ethical, environmental, health, societal, sustainability and safety constraints (b) the commercial and economic impact and (c) needs of customers and user in the design including human factors such as aesthetics and emotional needs.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Recognize and observe economic, ethical, sustainability, social, environmental, safety, manufacturability and political constraints imposed on design.
2. Recognize the impact of engineering solutions on society
3. Recognize cost-effectiveness
4. Perform engineering economics
5. Assess design related risks
6. Identify target customers and target market
7. Recognize and observe societal need
8. Identify users' needs
9. Satisfy the needs of customers

3.4 Engineering Practice (EP)

Engineering practice includes the ability to apply the previously gained scientific and engineering knowledge at practice. In doing so, the graduate should recognize and observe the environmental, ethical, legal and industrial constraints.

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

EP1. The ability to (a) recognize the domain of application of engineering knowledge and skills (b) utilize previously gained theoretical and experimental knowledge and practical experience in solving engineering problems and (c) apply new engineering techniques and suitable processes in engineering practice

Learning Outcomes

Graduates who possess this ability should be able to:

1. Write technical reports
2. Give oral presentations
3. Use recent technologies in system analysis and design
4. Predict system performance via computer simulations
5. Operate and control engineering processes
6. Perform process optimization
7. Conduct parametric studies
8. Use modern equipment and instrumentation.
9. Compare experimental findings with predictions from theory and explain any discrepancies
10. Assess the accuracy and quality of the obtained solutions
11. Recognize the limitations of the used methods and tools
12. Adapt to new technologies

EP2. The ability to (a) recognize the relevant codes of practice and the ability to work within the standards of the industry (b) adhere to professional and ethical standards, (c) recognize the legal obligations in engineering practices, including safety, personnel and environmental issues and (d) promote sustainability.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Recognize codes of practice
2. Implement industry standards
3. Recognize the responsibility within the national as well as the international guidelines.
4. Adhere to codes of ethics pertaining to a given discipline
5. Make decisions while observing ethical implications
6. Understand professional conduct
7. Recognize legal obligations and the consequent responsibilities.
8. Implement legal and regulatory requirements considering public health and safety in engineering activities
9. Follow environmental standards and regulations that must be addressed in engineering applications and practice
10. Recognize the need for sustainability

EP3. The ability to (a) manage engineering projects and (b) understand the nature of entrepreneurship.

Learning Outcomes

Graduates who possess this ability should be able to:

1. Implement work breakdown structure (WBS) and fundamentals of project management

2. Use scheduling technique tools in project planning stage
3. Recognize project organization and contracts
4. Develop project cost and cash flow
5. Monitor project in term of cost and time.
6. Recognize intellectual property and contractual issues

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

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