The Assessment of Learning Outcomes in Chemical Engineering Education: A Case Study from Saudi Arabia

Ahmed Abasaeed, Abdullah Alsadaawi, Saeed Al-Zahrani and Abdelhamid Ajbar*

Abstract— This paper presents the main features of a study carried out by the higher education authority in the kingdom of Saudi Arabia for developing a practical framework for formulating and assessing learning outcomes in chemical engineering education. The proposed learning outcomes were based on a compilation of different international accreditation frameworks. The formulated learning outcomes were grouped into four learning areas: (1) engineering sciences and foundation chemistry, (2) engineering analysis and investigation, (3) engineering design and (4) engineering practice. The paper also presents the main elements of a proposed standardized exit exam to test the developed learning outcomes. A table of specification was constructed that maps the developed learning outcomes with the test questions distributed over various learning levels (knowledge and comprehension, application and analysis, synthesis and evaluation). The table of specification allows the transformation of the developed learning outcomes into balanced questions to be used in the exit exam. The paper also discusses the implications of the proposed plan on the chemical engineering education in the kingdom and the concerns that are raised by the different stakeholders.

Keywords— Assessment; learning outcomes; exit exam; chemical engineering; Saudi Arabia.

I. INTRODUCTION

The engineering education environment is changing as information and communication technologies are having greater impact, and innovation is becoming increasingly essential. Companies today operate in a highly competitive environment, and in order to stay ahead of competitors, they are more inclined to value engineering graduates who possess a variety of non-technical qualities, in addition to the technical know-how for the job. Employers as well as academic accreditation entities are putting pressure to incorporate sound assessment techniques into engineering programs. Therefore, the assessment of learning outcomes has become a primary focus for engineering education in today’s competitive environment [1-2].

The outcome-driven assessment process, if carefully designed and implemented, can be useful at different levels. It can provide critical information on whether graduates have acquired the knowledge and skills defined by predetermined educational objectives. The assessment process can also convey useful formation to faculty and administrators on the effectiveness of the design and delivery of the educational program. It can also develop, in the long term, instruments to obtain comparable information on what students actually learn across different engineering colleges [3-4].

Quality assurance requirements, the primary drivers of assessment, are likely to be more imperative in third world countries. Engineering education in the kingdom of Saudi Arabia, for example, is less than half-century old. However, with the large expansion of the industrial sector as result of oil revenues, the country has seen a large increase in its engineering colleges, both public and private. Currently, the Kingdom has 21 public and 3 private universities offering engineering education. More than half of these engineering colleges are less than five years old. This rapid expansion was, however, not met with adequate assessment of student learning outcomes. Although a number of engineering colleges are accredited, there are sustained complaints from the industry about the unsuitable quality of the educational product compared to the demands and expectations of the labor market. The country ministry of higher education strongly encourages the universities to seek accreditation. However, private and newly founded public engineering institutions present real challenges to the higher education authorities as they try to maintain acceptable quality standards in their curriculum and products. In attempt to tackle these challenges, the ministry of higher education has launched a study to implement an exit exam for the engineering graduates across the country. The study was carried out over a period of two years and involved in the first step the elaboration of a “qualifications framework”. This was followed by the setting up of the exam structure. The authorities have also decided to implement the exit exam, on a trial basis, starting from the first semester of the next academic year (2014-2015). The objective of this paper is to provide and discuss details of this study as applied to the chemical engineering education.

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It should be noted that few countries in the world (e.g. Colombia) [5] impose a mandatory testing of graduating engineering students. But large-scale voluntary direct assessments via standardized tests are carried out by various nongovernmental assessment agencies in many countries [6-9]. These direct evaluation tests cover both generic competencies (e.g. reading, writing, mathematics and critical thinking) as well as technical skills. Other experiences of assessment use popular alternatives like ‘curriculum-embedded’ assessments and student portfolios [9-12].

II. RESEARCH METHODOLOGY

The study carried out at the request of the higher ministry of education in Saudi Arabia lasted two years and involved essentially the following tasks. The first stage involved an extensive review of available literature on the development of frameworks for learning outcomes in engineering education in order to compile previous related works, experiences, and lessons learned. The literature review covered experiences from various countries worldwide. The review also covered independent and important projects on learning outcomes such as the Accreditation Board for Engineering and Technology (ABET) [13], Conceiving- Designing- Implementing-Operating (CDIO) [14], European Accredited Engineer framework (EUR-ACE) [15], Assessment of Higher Education Learning Outcomes project (Tuning-AHELO) [16], UK standard for professional engineering competence (UK-SPEC) [17], standards for Engineers Australia (EA) [18], National Academy of Engineering (NAE) [19] and International Engineering Alliance (IEA) [20]. The second task involved the development of a local framework for engineering learning outcomes for various disciplines while the final task consisted in the development of the structure of the proposed exit exam. In the course of the study, the products of each stage were reviewed locally and by international experts through several workshops organized by the ministry.

III. PROPOSED FRAMEWORK

Chemical Engineering (ChE) skills include the knowledge of basic sciences, foundation chemistry, general engineering fundamentals and physical & chemical processes. Chemical engineers apply, in a well-integrated manner, these areas of knowledge as well as the acquired soft skills in the analysis, design and ultimately the operation and control of chemical plants while maintaining and preserving codes of practice, ethics, safety, health, economics and environment [21-25]. The proposed framework for learning outcomes was organized into four “learning areas” namely: engineering sciences, engineering analysis and investigation, engineering design, and engineering practice. Within each learning area, the content is further defined by a set of abilities. Each ability is composed of two major parts:

• The ability statement which broadly defines what an engineering graduate in his field/discipline should know and be able to do.

• The descriptive statements of the learning outcomes (LO) associated with the ability. These LOs describe in greater detail the knowledge and skills eligible for testing [26].

The following is a description of these abilities followed by the description of the main features of the proposed standardized exit exam.

A. Learning area: Engineering sciences and foundation chemistry

A.1 Ability (ChE1): The ability to demonstrate knowledge in foundation chemistry and fundamentals of chemical engineering.

Associated Learning Outcomes:
Graduates who possess this ability (ChE1) should be able to:
1. Describe and apply the basics of organic and inorganic chemistry.
2. Use concepts of units and dimensions; state major process variables; use physchrometric charts; perform basic material and energy balances.
3. State the first and second law of thermodynamics and their implications; utilize 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; identify causes of materials failure and imperfections.

A.2 Ability (ChE2): The ability to demonstrate knowledge of physical processes encountered in chemical engineering practice including the various separation process.

Associated Learning Outcomes:
Graduates who possess this ability (ChE2) should be able to:
1. Describe the fundamental, the physical meaning and the equations governing these processes; explain fluid statics and dynamics; recognize the differences between flow through annulus, submerged bodies and porous media.
2. Define and distinguish the basics of physical transfer processes and the factors that affect transfer and diffusion processes.
3. Apply the fundamentals of stage operations using phase diagrams and phase equilibrium, and describe the main factors affecting them.

A.3 Ability (ChE3): The ability to demonstrate knowledge of chemical processes encountered in chemical engineering practice and the implications of reaction kinetics on them.

Associated Learning Outcomes:
Graduates who possess this ability (ChE3) should be able to:
1. Use reaction stoichiometry and rate equations for irreversible and reversible reaction for both single and multiple reactions.
2. Understand the concepts of conversion, selectivity and yield.

A.4 Ability (ChE4): The ability to demonstrate basic knowledge of control systems used in chemical
plants.

Associated Learning Outcomes:
Graduates who possess this ability (ChE4) should be able to:
1. Understand process control structure and the concepts of set points, disturbances, controlled, manipulated variables and transfer functions.

B. Learning area: Engineering analysis and investigation

B.1 Ability (ChE5): The ability to identify, formulate, analyze and solve common chemical engineering problems including physical and chemical processes or units.

Associated Learning Outcomes:
Graduates who possess this ability (ChE5) 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 and/or using suitable computer simulation packages and software.
2. Identify and utilize the limitations imposed by thermodynamics on processes; apply the proper equation of state and proper analysis of phase and chemical equilibria; examine the performance of power cycles.
3. Quantify the implications and differences in flow regimes; 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 the flowing fluid properties.
4. Calculate heat and mass transfer coefficients; estimate the properties and role of insulating materials on heat transfer; 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 absorbers and distillation columns.
6. Appreciate the implications of changes in temperature and pressure on ideal reactors; perform material and energy balances using rate expressions; determine reaction kinetics from experimental data.
7. Devise proper control structures for chemical units; design PID controllers; analyze closed loop performance.
8. Apply the basics of economic analysis such as profit, depreciation, profitability, cash flow, present value and alternative investment; recognize the vital importance of economic analysis in plant design.

C. Learning area: Engineering design

C.1: Ability (ChE6): The ability to design units, components and plants to meet specific needs while observing technical, environmental, economical, societal, ethical and safety constraints.

Associated Learning Outcomes:
Graduates who possess this ability (ChE6) 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 on the design of piping systems and pumps.
3. Use proper energy equations and codes & standards to calculate energy requirements for a plant using equipment, such as heat exchangers and evaporators.
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)

C.2 Ability (ChE7): The ability to utilize experimental data, software, empirical equations and rules of-thumb in the design of chemical engineering units.

Associated Learning Outcomes:
Graduates who possess this ability (ChE7) should be able to:
1. Interpret experimental data for the benefit of the design.
2. Use empirical equations and rules of thumbs in the design of chemical engineering units.

D. Learning area: Engineering practice

D.1 Ability (ChE8): The chemical engineer must demonstrate an understanding of professional ethics, codes and standards, safety, health, control, HAZOP analysis, costing, management and sustainability as well as knowledge of contemporary issues and modern developments in the chemical engineering field.

Associated Learning Outcomes:
Graduates who possess this ability (ChE8) 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.
3. Recognize the new development in chemical processes, new analysis techniques and new software in the chemical engineering field.
4. Demonstrate sensitivity to preserving clean environment.

IV. PROPOSED TEST STRUCTURE

The proposed test is paper based, planned over a 3 hours session and consists of a total of 50 multiple choice questions. The test is open to holders of a bachelor degree in Chemical Engineering as well as students in the final year of such programs. Books, lecture notes, or similar materials are not allowed in the test. Necessary reference sheets, equations and relevant data are provided if needed. The detailed structure of the test is clarified with the construction of the Table of Specifications (Table 1). The table of specifications is a map that facilitates the transformation of the developed learning outcomes into balanced questions.
The first column of the table shows the learning area, namely (engineering sciences & foundation chemistry, engineering analysis & investigation, engineering design, engineering practice). The second column indicates the alpha-numeric code assigned to the ability, as outlined in the earlier section. The third column contains the codes of learning outcomes as specified in the previous section. Different learning outcomes are grouped – if necessary – according to question allocation requirements. The need for grouping some learning outcomes stems from the fact that the number of learning outcomes could exceed the suggested maximum number of questions in a particular learning area. The grouping of complementary learning outcomes would ensure that at least one learning outcome in a particular group will be tested.

The forth column indicates the number of questions allocated to each learning outcome group. In the present case, 50 questions are included in the test to be conducted over 3 hours. The fifth column, distributed over three learning levels (knowledge & comprehension, application & analysis, synthesis & evaluation), specifies the question distribution among the three learning levels. For example, there are 9 questions assigned to the first LO group (ChE1-01 to ChE1-04) of the first ability (ChE1). Four questions are allocated to the first learning outcome (ChE1-01). Two of these four questions are assigned to the first learning level (knowledge & comprehension) while the other two questions are assigned to the second learning level (application & analysis). It is important to note that the distribution of questions among the learning outcomes follows a careful process which ensures an adequate coverage for different learning areas (vertical allocation) as well as for various learning levels (horizontal allocation). In this regard, the distribution of questions among the three learning levels is 13 questions (26%) for knowledge & comprehension, 23 questions (46%) for application & analysis, and 14 questions (28%) for synthesis & evaluation. The distribution, on the other hand, of questions among the four learning areas (including foundation chemistry) is 17 questions (34%) for engineering sciences, 16 questions (32%) for engineering analysis & investigation, 11 questions (22%) for engineering design, and 6 questions (12%) for engineering practice.

The sixth column shows the distribution of questions among different subject areas as well as the total number of questions. The seventh column shows the percentage of questions allocated to each learning area while the eighth column indicates the average question time (in minutes) as calculated from the preceding two columns. This average represents only a general guidance as it is understood that some questions may require longer or shorter time.

V. CONCLUSION

This paper has presented the essential features of an ambition plan by the higher education authorities in Saudi Arabia to set up an exit exam for the Kingdom engineering graduates. The plan was set up after two years of extensive study by local staff and international reviewers. The paper presented the main elements of this plan as applied to the chemical engineering discipline. The plan has been approved by the higher education authority in the country and is due to be implemented on a trial basis within one year. The remaining of the work on this plan focuses now on forming a comprehensive database of questions that conform to the table of specifications that was established in this study.

It is understood that the plan, if carefully implemented, could have a positive impact on engineering education. However, there are a number of issues that are still controversial in this plan, and are still under debate by the different stakeholders. The exam results may serve to rank the different universities which could affect government spending on them. Newly formed universities are concerned that their structures are not yet solid enough to compete with the other well established colleges. Students and parents are concerned that the exam results, if communicated to employers, could affect their chances for recruitment. Faculty members raise the concern that the students will ultimately focus their efforts on studying for the exit exam rather than for the actual curriculum. Multiple choice questions may be inappropriate for testing high level cognitive skills. All these concerns are valid and are still being discussed within the ministry. The results of the first exam are expected within a year, and will provide valuable feedback that may correct any shortcomings of this experience.

ACKNOWLEDGMENT

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REFERENCES


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