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Learning Outcomes Alignment across Engineering Core Courses

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Abstract**—**In this paper, a team of faculty members of the Petroleum Institute in Abu Dhabi, UAE representing six different courses across General Engineering (ENGR), Communication (COMM), and Design (STPS) worked together to establish a clear developmental progression of learning outcomes and performance indicators for targeted knowledge, areas of competency, and skills for the first three semesters of the Bachelor of Sciences in Engineering curriculum. The sequences of courses studied in this project were ENGR/COMM, COMM/STPS, and ENGR/STPS. For each course's nine areas of knowledge, competency, and skills, the research team reviewed the existing learning outcomes and related performance indicators with a focus on identifying linkages across disciplines as well as within the courses of a discipline. The team reviewed existing performance indicators for developmental progression from semester to semester for same discipline related courses (vertical alignment) and for different discipline courses within the same semester (horizontal alignment). The results of this work have led to recommendations for modifications of the initial indicators when incoherence was identified, and/or for new indicators based on best practices (identified through literature searches) when gaps were identified. It also led to recommendations for modifications of the level of emphasis within each course to ensure developmental progression. The exercise has led to a revised Sequence Performance Indicator Mapping for the knowledge, skills, and competencies across the six core courses.

Keywords**—**Curriculum alignment, horizontal and vertical progression, performance indicators, skill level.

I. Introduction

In recent years, the United Arab Emirates (UAE) has witnessed a 38% increase in the number of students enrolled in engineering degree programs, a positive response to national calls to develop an "elite corps of scientists, engineers, and technicians" [1]. The need for locally-born engineers within the oil and gas industry, and in particular the Abu Dhabi National Oil Company (ADNOC), is especially critical. The Petroleum Institute (PI) is a leading engineering university located in Abu Dhabi in the UAE. Established in 2000 by Emiri decree and enrolling its first students in 2001, the PI educates engineers who primarily go on to work for ADNOC and its group of operating companies. The push for locally-born engineers, known as Emiratization, has seen a large increase in the number of entering engineering students to the PI. This rapid increase in enrollment includes demographic changes in recent cohorts of entering engineering students, with larger numbers beginning their studies underprepared in the areas of mathematics, science, and the academic skills needed to succeed in engineering studies, leading to the need for a more coherent approach to their engineering studies, particularly in the first two years of the curriculum. Offering degrees only in engineering, the PI has an annual undergraduate enrollment of just over 1500 students. As an English medium university in an Arab country, nearly 100% of students have English as a second language. In addition, a large percentage is among the first generation in their family to attend university. Most of the students are coming from UAE government high schools that primarily promote a concept of learning through memorization. Curricular innovation within the College of Arts and Sciences (CAS) of the PI, which offers common courses in the first two years of the undergraduate engineering degree programs, was initiated in response to identified needs within the student population, and as part of broader discussions taking place within ABET and national accreditation processes, along with institutional strategic planning efforts. The efforts have focused on providing opportunities for students to experience the creative nature of the engineering design process at an early stage in their education while simultaneously developing technical know-how, academic literacy, and professional skills such as project management, team-work and communication.

A key aspect of the efforts has been the creation of forums that help to break down departmental silos, bringing faculty from diverse disciplines together to discuss the concept of teaching students, not just subjects. The process has been guided by adoption of a student-centered outcomes based approach to curriculum design [2]-[5], the general concept of which is illustrated in Fig. 1. Student-centered curriculum design promotes a high level of student engagement, and thus deeper learning. Previous approaches that focused on a list of topics to be taught, or around the chapters of a textbook, all too often led to teaching that occurred without learning.

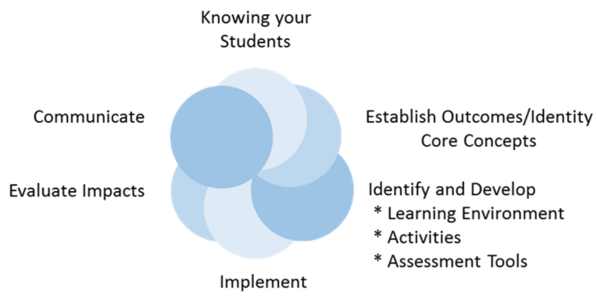

Fig. 1 Student-Centered Curriculum Design Framework, based on Brown, 2008 [4]; Nilson, 2010 [2]; Svinicki, 2004 [3], Wieman, 2010 [5]

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II. METHOD

Through the efforts described in this paper, we seek to illustrate how teaching and learning can become "synonymous sides of the same coin." [2]. We identified what we want our students to be able to do by the end of not a single course, but of a sequence of courses, ensuring that each course builds on previous courses and supports what is happening in concurrent courses, not only within a discipline, but also across disciplines. The process began with development of an understanding of what was happening across different departments within the same semester of a student's studies. The research involved faculty members of the CAS from six courses across different subject areas. We were brought together to learn what each other was doing in order to build a more comprehensive, holistic, coherent approach to the entire core sequence, one intended to enable success among the new generation of students. We begin Section III by discussing the structure of the approach taken. This will be followed by specific examples of outcome refinement that occurred and discussion of the final scope and sequence matrix developed. We will conclude with a brief discussion of the next stages of the process.

The curriculum development work focused on the *common knowledge, skills* and *competencies* being developed across the General Engineering (ENGR), Communication (COMM), Design (STPS) and Physics (PHYS) course sequences, both horizontally and vertically. These are required courses for all freshmen and sophomores. The work examined included topics, learning outcomes, and performance indicators related to areas such as teamwork, time/project management, ethics, information literacy, research skills, reading and writing. The sequences of the courses studied were ENGR101/COMM101, ENGR102/COMM151, and STPS201/PHY191. These sequences of courses are taken by engineering students at the PI in their first, second, and third semester of their Bachelor of Sciences (BSc) programs. We investigated the current alignment across the relevant areas, and examined the existing ENGR/COMM/STPS Course Learning Outcomes (comprehensive statements pertinent to the knowledge, skills and aspects of competence that a learner is expected to know and be able to do by the end of a particular course) and Performance Indicators (specific, measurable statements identifying the performance(s) required to demonstrate attainment of a Course Learning Outcome (CLO) or Student Learning Outcome (SLO), confirmable through evidence) for the different knowledge/skill/competency areas within a given semester (Horizontally) and across semesters (Vertically). A snapshot of the existing Arts and Science Sequence Performance Indicator Mapping is presented in Table I. It represents the sequence ENGR101/COMM101 that PI students take during the first semester of the BSc programs. The current matrix was used as reference for this initial task.

The nine knowledge/skill/competency areas covered in the sequences of courses reviewed in this project, along with their corresponding College of Arts and Sciences' program level Student Learning Outcome (SLO) are presented in Table II.

III. RESULTS

The first investigation performed in this work was to identify linkages between courses within a semester. This task consisted of checking whether the performances indicators in the two courses of a given sequence supported one another. For example, in the area "Design Process", we looked at the performance indicators in ENGR101 and in COMM101 courses, and we did not identify any linkages between these two courses.

TABLE I (A)
SEQUENCE PERFORMANCE INDICATOR MAPPING FOR THE SEQUENCE ENGR101/COMM101: KNOWLEDGE, SKILLS AND COMPETENCIES AREAS – LEVEL OF EMPHASIS – PERFORMANCE INDICATORS (BASED ON FALL 2014 SYLLABUS)

	Design Process SLO 3	**Research Skills** SLO 2	**Modern Engr. Tools** SLO 5	**Language & Comm.** SLO 7	**Project Mgmt.** SLO 8	**Teamwork** SLO 6	**Information Literacy / Critical Thinking** SLO 8	**Application of Math /Science** SLO 1	**Ethics** SLO 4
ENGR101	**L** Apply engineering problem solving approaches as a member of a team to solve engineering problems (B)		**L** Use tools and strategies to interface hardware and software (B)		**H** Actively participate in a cohesive, productive learning community (A) Assess his/her learning style and individual learning needs (A) Develop tools and strategies to succeed as an engineering student (e.g. time management, goal setting, study skills) (A) Actively participate in a variety of PI activities and utilize available resources € apply, evaluate, and adapt success strategies for current and future semesters (A)	**L** Demonstrate knowledge of Effective Teamwork through Self-evaluation of contributions (B)			**M** Highlight how the concepts of honesty and ethics are applied in education and the profession (A)

TABLE I (B)
SEQUENCE PERFORMANCE INDICATOR MAPPING FOR THE SEQUENCE ENGR101/COMM101: KNOWLEDGE, SKILLS, AND COMPETENCIES AREAS–LEVEL OF EMPHASIS – PERFORMANCE INDICATORS (BASED ON FALL 2014 SYLLABUS)

	Design Process SLO 3	**Research Skills** SLO 2	**Modern Engr. Tools** SLO 5	**Language & Communication** SLO 7	**Learner Training & Project Mgmt.** SLO 8	**Teamwork** SLO 6	**Information Literacy / Critical Thinking** SLO 8	**Application of Math/Science** SLO 1	**Ethics** SLO 4
COMM101		**H** Formulate a research question (B) Distinguish between quantitative and qualitative data (A) Identify the variables in a research question and how these might be measured (A) Choose and develop appropriate research instruments (A) Select and describe relevant data (B) Interpret data and make recommendations based upon the data (A) Analyze, evaluate and draw conclusions (B)		**H** Write academic reports and other project documents(B) Describe and summarize (academic) observations, arguments and ideas, and relate and evaluate them in writing (B) Present/deliver content orally (A) Give PowerPoint presentations directed at a specific audience (A)	**H** Take notes and synthesize information from a variety of resources (A)	**M** Demonstrate effective and constructive contribution to team (B) Demonstrate commitment to team and project (A) Work effectively in a team (A) Evaluate self and peers (A)	**H** Find and organize relevant sources of information about a specified topic in the library and on the World Wide Web (A) Demonstrate reflective and critical thinking skills (B) Read and think critically (B) Evaluate academic reading material (A)	**M** Present information and research data graphically (A)	**H** Plagiarism

TABLE II
KNOWLEDGE, SKILLS, AND COMPETENCIES AREAS

Knowledge/Skill/competency Area	Arts & Sciences Student Learning Outcomes (SLO)
Design Process	SLO 3
Research Skills	SLO 2
Modern Engineering Tools	SLO 5
Language & Communication	SLO 7
Project Management	SLO 8
Teamwork	SLO 6
Information Literacy – Critical Thinking	SLO 8
Application of Science and Mathematics	SLO 1
Ethics	SLO 4

The second task conducted was to determine whether a clear developmental progression existed across the semesters vertically. The descriptors of expected skill levels used in the Sequence Performance Indicator Mapping shown in Table I are presented in Table III.

TABLE III
DESCRIPTORS OF EXPECTED SKILLS LEVELS

Description	Descriptors Skill Level
Basic Level/Introduction	B
Applied Level/Developing	A
Expert Level/Independently	E

This task identified several inconsistencies of skill level expectation in the vertical progression from one semester to another in most areas. For example, in the Sequence Performance Indicator Mapping matrix, the performance indicator "Apply the engineering design process as a member of team to solve engineering problems" in the area "Design Process" in the course ENGR102 appeared with level "A" where it should have been at level "B" since students have not yet been exposed to this topic in previous courses in the vertical sequence: ENGR101. Throughout this exercise, existing incoherencies were identified and corrected to allow a coherent skill level progression vertically. Another type of inconsistency identified during this analysis was the level of emphasis of the *Knowledge / Skill / Competency* area in a given semester for a given course. The "Level of Emphasis" scale used in the Mapping is presented in Table IV. It allows instructors to have a clear vision of the importance of a specific Knowledge/Skill/Competency area in a given course.

TABLE IV
DESCRIPTOR OF LEVEL OF EMPHASIS

Description	Level of Emphasis
Low	L
Medium	M
High	H

The resulting Sequence Performance Indicator Mapping included all modifications to present a clear developmental progression for course learning outcomes and performance indicators across the semesters vertically from: Basic / Introduction (B) → Applied / Developing (A) → Expert / Independently (E). Another example presented hereafter is related to Arts & Sciences' SLO 6, "Ability to work in teams", which is listed as a course learning outcome in ENGR101, COMM101, COMM151, STPS201, STPS251 and PHY191. The assessment of this SLO in these courses did not lead to a quality assessment of how the student's competency developed over time. For example, in COMM101, students rated their teammates based on their contribution, timeliness, attendance, attitude, and cooperation. In COMM151, the peer review was based on academic, editorial, administrative and communication skills. In STPS201 and STP251, the rating was based on quality of technical work, ability to communicate, ability to provide leadership, effectiveness and commitment to project and team. The goal of the exercise was to instill in students' awareness, knowledge and skills in the area "Ability to work in teams" as they progress in their curriculum and raise their competencies to the level expected by their future employer, ADNOC. The results of the alignment exercise for SLO 6 are summarized in Table V:

TABLE V
ALIGNMENT OF THE AREA "TEAMWORK" HORIZONTALLY AND VERTICALLY

Courses	Teamwork (A&S SLO 6)
ENGR 101 (1st Semester)	**L** * Demonstrate knowledge of effective teamwork (B)
COMM 101 (1st Semester)	**M** * Make useful and effective contributions to process and products (B) * Collaborate and cooperate in a team (B) * Describe the stages of team formation with reference to personal team experience (A) * Review and develop performance of self on a team (B)
ENGR 102 (2nd Semester)	**L** * Make useful and effective contributions to process and products (B) * Collaborate and cooperate in a team (B)
COMM 151 (2nd Semester)	**M** * Make useful and effective contributions to process and products (A) * Collaborate and cooperate in a team (A) * Review and develop performance of self and others on a team (B) * Develop awareness of conflict resolution (B)
STPS 201 (3rd Semester)**	**H** * Make useful and effective contributions to process and products (A) * Collaborate and cooperate in a team (A) * Review and develop team performance (B) * Resolve conflict in a team setting (B) * Demonstrate knowledge of team roles (B)
PHYS 191 (3rd Semester)	**H** * Collaborate and cooperate in a team (A)
STPS 251 (5th Semester)	**H** * Make useful and effective contributions to process and products (A) * Collaborate and cooperate in a team (A) * Review and develop team performance (A) * Resolve conflict in a team setting (A) * Demonstrate knowledge of team roles (A)

IV. CONCLUSION

The deliverable for this work was a revised Sequence Performance Indicator Mapping matrix for the knowledge/skill/competency areas across the set of courses ENGR101/COMM101, ENGR102/COMM151, and STPS201/PHY191 that shows alignment and development both horizontally and vertically. This matrix establishes a clear progression of topics, learning outcomes and performance indicators for targeted skills and competencies across three semesters of core courses. It also establishes comparable assessment rubrics to be used across the courses, and presents course learning outcomes, performance indicators and assessment rubric models that could be used by other departments of the College of Arts and Sciences as reference for similar work. The next stage of the project will be to extend this matrix to include the junior and senior year engineering courses, with particular emphasis on the design sequence and the senior capstone project courses.

During this work, a team of PI faculty members representing six different courses worked together to establish a clear developmental progression of course learning outcomes and performance indicators for targeted skills and competencies across the first two years of an engineering curriculum. We engaged in lively discussions and gained as much through the process as we gave. For each program level student learning outcome (SLO) the team 1) reviewed existing Course Learning Outcomes (CLOs) and related performance indicators with a focus on identifying linkages across courses, gaps or redundancies, 2) reviewed existing performance indicators for developmental progression semester to semester, 3) recommended modifications to existing indicators and/or new indicators based on best practices (identified through literature searches), 4) identified the level of emphasis within each course, and 5) generated a revised set of CLOs and performance indicators under each program SLO. The exercise led to a revised Scope and Sequence Matrix for the knowledge, skills, and competencies across the six core courses. This document provides a clear demonstration of what students are expected to do, and be assessed on, in each course so that instructors of different courses can be aware of what skills and competencies have been, are being, or will be developed in other courses in this ENGR-COMM-STPS core sequence. Following completion of the comprehensive scope and sequence, the document was used to update existing course syllabi with the revised Course Learning Outcomes and performance indicators. The next stages of the process will involve identification of appropriate assessment venues and development of unified performance level descriptors and scoring rubrics to be used across the sequence of courses. The complete mapping will then be shared with the engineering departments so that the alignment can be extended vertically up through the senior design courses.

While the product is important, what was identified as the most valuable component of this process was bringing together faculty from diverse disciplines to share their knowledge and experiences with one another, helping to create a cross-departmental understanding of the overall content and intended learning outcomes for the sequence of courses taken by all engineering students at the PI during their first three semesters. We were then able to take our complete understanding of the desired comprehensive educational experience back to our departments, further expanding awareness in ways that will better provide a forum for promoting student success.

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