Integration of Engineering Practice into the Curriculum

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Abstract

In pursuit of excellence in engineering education and positioning itself for ABET accreditation, the College of Engineering (CoEng) at the University of Tabuk (UT), Tabuk located in Saudi Arabia has integrated a strong engineering practice component into its educational program curricula. This component relies on a series of courses that foster a variety of soft skills wrapped around four design project courses and two four-week practical training periods at a company or research facility. Furthermore, students at the senior level are strongly encouraged to undertake realistic projects. In this paper, we describe our experience with three groups of students from the Electrical Engineering (EE) Department who undertook projects sponsored by the Sensor Networks and Cellular System (SNCS) Research Center at the UT. The projects were complementary and multidisciplinary in nature giving the students the opportunity to get familiarized with product design, testing, integration, and deployment. The students were to design and build as well as use off-the-self components. The products of the three student teams are then integrated into an existing device, Mariner, to give it added capabilities. Mariner consists of a marine platform used for monitoring fish habitat parameters in the Red Sea. The students have made several public poster presentations throughout the year to both sharpen their communication skills and seek input. At the end, each group provided a comprehensive report, made a public presentation, and field demoed their products. Students were accountable not only for their products as subsystems of Mariner, but also for the proper operation of Mariner as a system of systems. The evaluation was made by both faculty advisors and mentors from SNCS and focused on the extent to which (1) design specifications have met, and (2) students have mastered relevant program outcomes. The result was a marketable experience that instilled in students the sense of responsibility and self-confidence. The main contributions of this paper are informed integration of engineering practice into curriculum, meaningful and practical design experience, effective evaluation and assessment of students and their work.

Introduction

Saudi, as in the case of any fast developing country, has a tremendous need for capable engineers to address the needs of its various economic sectors. While there are clear emerging research and development activities at universities and major companies and research centers, there is an immediate need for a competent workforce that is readily available to participate in the development of the Saudi economy. Among the much needed skills for this workforce are design to specifications, manufacturing, assembly, testing, integration, and deployment. These skills are necessary to quickly, and efficiently and economically develop products that address the immediate needs of the fast developing Saudi population.

The lack of an educated workforce with the above mentioned skills, has been the result of the perception that these skills are low level and do not necessary rise up to the prestigious engineering status. Thus, universities and colleges have, to a great extent, dismissed them from their curricula. However, recently, with the efforts of the government in creating a knowledge based economy, tremendous efforts are being invested in instilling the spirit of product development and the ensuing commercialization which in turn requires the skills mentioned above.

To effectively play its role in the new era of knowledge based economy and positioning itself for ABET accreditation, CoEng at UT has reviewed its engineering curricula. This review was made in light of its current student outcome achievement, employment outlook, economic trends, and governmental policies and priorities focusing on resource diversification and the creation of jobs for the sought knowledge economy. The result of the review entailed, among other things, strengthening the engineering practice components of the curricula with the intent to form engineers that would readily serve the Saudi economy in terms of making sustainable products at a reasonable cost that are meaningful to the Saudi citizen. Furthermore, a secondary aim of the revision was to interweave seamlessly an assessment process that informs about student attainment of intended outcomes and lends itself to continuous improvement.

Universities have routinely revised the engineering practice component of their educational program curricula in order to stay current and increase the employability of their graduates. To this end, some universities have focused especially on the design project experience at the senior level and some others have taken a more aggressive approach to impact a cluster of courses labeled as the “professional practice component” or “engineering practice component” as in the case of UT. In [1], the authors have described the development of a new course at the sophomore level that fosters leadership and communication skills for their civil engineering program. In [2], the authors have described the introduction of a course in innovation and entrepreneurship that can be taken by both graduate and undergraduate students thus fostering interdisciplinary work. In [3], the authors have described changes in the senior design project that fosters industry sponsored multidisciplinary projects. The review undertaken by UT, encompasses changes as in [1-3] and more such as adding a mandatory field experience. In this paper, the revised engineering practice component is explained, the assessment and evaluation processes are discussed through a sample of student projects, and finally conclusions and recommendations are given.

Basic Elements of the Revised Engineering Components

While the changes have impacted the civil, electrical, and mechanical engineering (CE, EE, and ME) programs equally, the basic elements of the revised engineering practice component of the EE program are two lower division design courses (EE205 and EE215), two upper division (senior) design courses (EE495 and EE496), and a summer training course (EE399) as shown in the following table.

Table 1. EE Program Revised Engineering Practice Component

Course Title		Code/ No.	Credit Hours
Soft Skills			
1.	Communication Skills	COMM001	2
2.	Computer Skills and its application	CSC001	3

3.	Learning, Thinking, and Research Skills	LTS001	3
Shop Skills			
4.	Engineering Drawing and Graphics	ENG201	3
5.	Production Tech. and Workshops	ENG202	3
6.	Measurement and Instrumentation	EE204	2
Professional Skills			
7.	Engineering Economy	ENG214	2
8.	Engineering Management	ENG215	2
Design Skills			
9.	Engineering Design 1	ENG205	3
10.	Engineering Design 2	ENG213	2
11.	Graduation Project I	EE495	1
12.	Graduation Project II	EE496	3
Practice Skills			
13.	Summer Training	EE399	2

In addition to the basic courses, there are eight supporting courses covering soft, shop, and professional skills. The courses are distributed in the curriculum in order to permit the students gradual learning and application of the concepts:

- In Engineering Design 1 and 2, in addition to learning the elements of design, students are exposed to a variety of soft skills such as communication, teamwork, and ethics in support of program outcomes which are derived from ABET student outcomes.
- In Graduation Project I, student prepare a comprehensive proposal ending with design specifications and in Graduation Project II, students build the corresponding physical device (the product). Both projects required a comprehensive written report as well as a final public oral presentation as well as demonstration of the product. The design projects are accompanied with a series of seminars in which students are exposed methodically to the variety of soft skills required by student outcomes. These seminars are also used to perform both direct and indirect assessments of student attainment of selected soft skills.
- In the summer training course, students spend eight weeks at a company or a research facility learning and practicing first-hand from professionals. Students are closely mentored and their performance is assessed by both the faculty advisor and a mentor from the company or the research facility. At the end of the course, students submit a report as well as make a public presentation.

A Sample of Graduation Projects

SNCS has developed Mariner (Fig. 1), a platform deployed in the Red Sea, that collects oceanic parameters affecting marine life. Mariner collects data through multiple underwater sensors, stores it in a data logger, and sends it to a monitoring station at SNCS for analysis. Mariner stays afloat unsupervised in harsh conditions for extended periods of time reaching six months at a time. It has already gone through four upgrade phases (generations). During the fifth upgrade phase, three student teams from EE have been selected to undertake specific tasks in the context of their Graduation Projects I and II. These tasks entail the development of subsystems that give Mariner added capability. In other terms, the students will be involved in upgrading a system of systems (Mariner).

Figure 1. Mariner

In fulfilling their tasks, student teams have engaged in various aspects of design, manufacturing, assembly, integration, testing, and deployment at a variety of levels. Many hardware and software components needed for their parts have been ordered from companies and distributors located overseas. This has put the extra burden on them to be precise and accurate with regard to their orders to avoid loss of time that would adversely affect their work schedule especially the synchronization of the of the various activities during the phases of testing and integration. The project teams are:

- **Alarm Team (AT):** A group of three students responsible for remote intrusion detection and warning.
- **Propulsion Team (PT):** A group of four students responsible for the movement and wireless control and command of Mariner during its deployment in the Red Sea.
- **Data Communication Team (CT):** A group of three students responsible for data collection from sensors, storage, and wireless transmission to the control center at SNCS.

The mechanical structure of Mariner offers limited space for mounting the subsystems developed by the teams and therefore optimization of the designs and meticulous planning for their placement on Mariner is crucial in order to preserve Mariner's equilibrium at about the water-line level. Therefore, communication among teams is as important as communication among the team members especially in the integration phase. Furthermore, each subsystem needs to be tested independently during development as well as in conjunction with the other subsystems upon final installation on Mariner. In what follows the task of the teams are explained:

Alarm Team

Table 2. Task of AT

Problem Statement	Project Goals	Design Specifications
Mariner needs to be deployed remotely in the Red Sea to collect data for an extended period of time that may be up to six months. There is a need for providing a highly effective wide area intrusion detection and warning (IDW) solution to protect Mariner and its data.	The IDW must: - Create a protection volume (bounding box) around Mariner - Sound an audible alarm - Emit a warning light - Send sms text to SNCS - Be remotely accessible through web	The design must meet the following technical specifications: - Bounding volume radius: 10<BVR<15 m - False alarms: FA<5% - Cost: C<2,500 SAR - Power source: Solar - Safety: harmless to fish and humans (below the dB level imposed by regulations governing Humans and wildlife)

Propulsion Team

Table 3. Task of PT

Problem Statement	Project Goals	Design Specifications
Mariner needs to be deployed in the Red Sea to collect data from a variety of locations. For this purpose, there is a need for Mariner to have the ability to move autonomously, to be steered wirelessly, and to remain fixed at a given location upon receiving a command (anchor function).	Mariner must be able to: - Move to a desired location (point in the Red Sea) upon command - Stay at a given location despite external disturbances (wind, waves, etc…)	- Maximum radius of wireless/autonomous movement zone: R_{max} < 1,000 m - Movement speed: 100 < v < 150 m/min - Positioning error: e < 5 m - Power source: electric/solar - Installation: detachable drive

Data Communication Team

Table 4. Task of CT

Problem Statement	Project Goals	Design Specifications
Mariner needs to be deployed remotely in the Red Sea and collects data for an extended period of time that may be up to six months. During this time Mariner will be collecting data through five sensors and a sonar. Thus,	Mariner should be able to: - Store the sensor and sonar data locally - Send the sensor and sonar data collected wirelessly to SNCS	- Data collection frequency: 1 sec to 5 min intervals - Minimum Capacity: 4 MB (100,000 readings) - Data wireless transfer rate: as permitted by 4G LTE

there is a need for mariner to both store its data locally as well as send it to SNCS wirelessly.		- Data loss < 10%

A cumulative budget of 93,750 SAR ($25,000) has been allocated for the whole upgrade. The actual cost was about $23,000.

Table 6. Budget

Team	Hardware and Software	Other (stipends, travel, etc…)	Training, travel, conference registration, etc…
AT	$746.00	$11,514.98	$2,816
PT	$4,377.98		
CT	$3,690.00		
Total	$23,145		

Project Impacts and Considerations

During their work and especially during the implementation phase, students have been exposed first hand to several considerations:

Social Considerations. When first tested in the Red Sea, Mariner was deployed on the shore in front of a major resort. Care was taken to ensure that students teams are sensitive to the privacy of the families occupying the bungalows on both parts of the resort.

Safety Considerations. Each team had its own perspective on what safety measures need to be taken. The Alarm team had, for example, to ensure that the alarm sound level is safe for both human and animals (fish and birds).

Environmental Considerations. The propulsion team, to reduce the sound level, has chosen an efficient electric motor powered by a regular car battery that is charged by a solar panel.

Legal Considerations. All teams have been made aware of the protocol followed in order to secure the permission from the government to deploy Mariner in the Red Sea as well as the technical requirements imposed such as the communication frequencies allowed.

Manufacturability Consideration. The design of some parts of Mariner have been altered and other had to be built from scratch. In both cases care has been taken to ensure seamless integration.

Assimilability Considerations. Some teams have manufactured parts locally and some others have acquired them from overseas. Care has been taken to, in both cases, ensure that parts fit together as intended. Furthermore, the teams that ordered parts from overseas needed to understand the protocols and policies of shipping as required by the customs services.

Sustainability Considerations. All systems and subsystems of mariner operate on solar energy thus avoiding the exhaustion of any natural resources. Furthermore, Mariner itself is a device that provides environmental, social, and economic benefits while protecting public health. The data received from Mariner helps ensuring clean habitat for fish which in turns contributes to the food supply.

Assessment and Evaluation

For assessment and evaluation, several forms were developed, among which are the forms shown in Appendices A and B. The student outcomes are evaluated in three ways throughout the project:

- *Student Self-Evaluation (Indirect/Summative).* The student evaluates himself indirectly with respect to each outcome. Students are given forms listing all ABET student outcomes and are asked to reflect on them and address them in writing. They are also asked to evaluate themselves on each outcome and record their level of achievement in a specially designed form.

- *Advisor and Mentor Evaluation (Indirect/Summative).* The advisor and mentor also evaluate the level of attainment of the student outcomes for all students in all outcomes using probing questions as in Table 7 and record their level of achievement in a specially designed form.

- *Committee Evaluation (direct/Summative).* Student mastery of the outcomes is evaluated directly based on the project report, oral presentation, and the product demonstration. The examining committee includes two faculty, the advisor, and the mentor. For further clarification, the committee may also ask probing questions, as shown in Table 7, regarding each outcome and record their evaluation in a specially made form.

Finally, results are processed and recorded in the form shown in Appendix A. Once this form is completed for all students, the results are analyzed and recommendations for improvement are made. Furthermore, the results can be further treated and recorded in the form shown in Appendix B.

Probing Questions

The following table shows probing questions that have been developed for a sample of student outcomes. These questions serve only as guidelines and maybe altered to yield consistent responses.

Table 7. Sample of Probing Questions

Outcome	**Probing Questions**

(b)	an ability to design and conduct experiments, as well as to analyze and interpret data	• What parameters have been measured • What experiments have been designed. Why? How? • How the results were analyzed? Why? • What were the results of the analysis? • What conclusions have been drawn? • Are the conclusions consistent with expectations (theory)?
(c)	an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	• What has been designed? • What considerations have been taken into account? Why? • Were design specifications met? How? • What constraints have been taken into account? Why? How
(d)	an ability to function on multidisciplinary teams	• What disciplines were necessary for the completion of the task (subproject)? • What was the role of each team? • What was the role of each team member? • What support has been received from the other teams? Why? How?
(g)	an ability to communicate effectively	• How was the task planned? • What were the duties of the team members? What is the rational for duty distribution? • What conflicts have been encountered at the task level? At the project levels? How did they get addressed? • What challenges have been encountered in procuring parts? How did they get resolved?

(h)	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	• What is the impact of the subsystems (alarm, propulsion, communication) as well the overall system (Mariner):
		    o At the local level?
		    o At the global level?
		• What is the impact of the subsystems (alarm, propulsion, communication) as well the overall system (Mariner) on:
		    o Society
		    o Economy
		    o Environment

Student Outcome Attainment

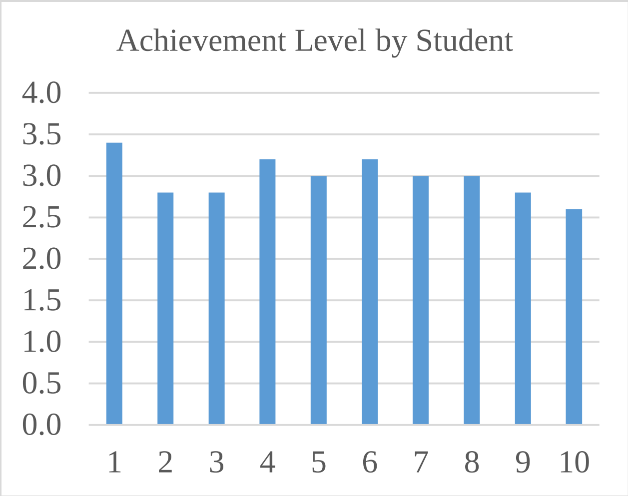

Figure 1. Achievement Levels for 10 students

On a scale of 5, 60% of the students have attained the outcomes at a level of 3.0 or more, thus exhibiting a satisfactory achievement. This is while 40% of them have achieved at levels between 2.5 and 3.0. The rubric used for remedial actions calls for actions when achievement levels are below 2.5, monitoring and deferring actions when achievement levels are between 2.5 and 3.5, and no actions necessary when achievement levels are above 3.5. Furthermore, no actions will be implemented at the present time.

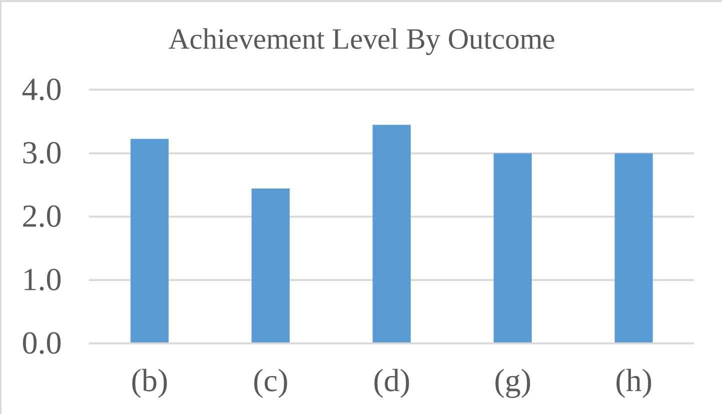

Figure 2. Outcome Achievement Levels

With respect to the outcomes, 80% are achieved at a level of 3.0 or more. Only one outcome, outcome (c), is achieved at a level of 2.4 (just below the threshold of 2.5). Under normal circumstances, immediate corrective actions are necessary in the case of outcome (c). However, since the level achieved is very close to the threshold, then in this case too, action is differed.

Clearly outcome (c) has been very challenging for students as it requires a variety of skills such as communication and working in and with groups as well as abilities such as manufacturing, assembling, integrating, and testing. It was also clear that:

- While students were able to communicate adequately and solve issues within their individual groups, they faced many challenges to reconcile group differences such as gathering at the same time to plan the integration phase.
- Two of the three groups had to order or bring equipment from countries in a variety of continents. This has created legal challenges that students struggled to overcome.
- Most notably, once the equipment was secured, at least one group had challenges in assembling the parts because of language issues and had to resort to seeking training by the vendor and incur extra cost.

All these and more such as administrating the project budget, requesting the permission from the coast guard to test the device in the Red Sea in time, and logistics related to testing during cold weather. Despite all this, students seem to have enjoyed the experience and while they feel they could have done better, they thought they are better prepared for real world projects.

Post-Project Reflections

A post-project meeting was held that included all student groups, and faculty advisors and researcher mentors from SNCS. Students were clearly satisfied with the experience that spanned the two semesters of the 2015 academic year. They especially appreciated the fact that the projects were assigned to them and that they weren't of their choosing. They believed this made them learn and apply many new concepts that are new to them. Furthermore, they also believed that having to manage their own budgets and determine their needs of equipment and actually make the purchase has built their confidence in impactful decision making. They also appreciated being exposed to the processes of seeking the variety of permissions from governmental agencies in order to legally test Mariner in the Red Sea after all subsystems (student parts) have been integrated. All student groups wished that:

- They had more time to do more testing of Mariner in the Red Sea after final integration of their parts.
- They had more opportunities to meet and discuss the testing protocol and deployment of Mariner in the Red Sea.

On the other hand, faculty and mentors alike have suggested several ideas to improve the student experience including:

- Allocating a student from each group to serve as a permanent "Liaison" in the other groups. This way, each group will know more about the work of the other groups.
- Involving students in the writing of papers such as this one.
- Allocating a session with all groups to brainstorm about further capacity and capability enhancements of Mariner that may be formulated as projects for other student groups in the future.

The faculty advisors have also expressed the need for further refining their assessment instruments and tune them to take full advantage of the benefits of realistic projects.

Discussion

The integration of engineering practice into the curriculum through realistic problem solving as encountered in the projects described in this paper appears to be very promising. However, for this to be meaningful academically, premeditated assessment and analysis must be done to inform student mastery of the achievement of outcomes. Specifically, both faculty and mentors have recognized the need for:

- Determining the exact capabilities and skills that the projects support and mapping them to student outcomes prior to starting the projects.
- Monitoring the attainment of student outcomes through time during the project sequence. This, rather than the snapshot that occurs at the end.

- Use adequate mix of direct/indirect and formative/summative assessments to gauge student performance and especially outcome attainment.
- Insuring sustainability of the experience and expanding it to include more student teams especially female teams. It is worth mentioning that the college of engineering is currently male only. However, there are opportunities to form multidisciplinary groups through including female teams from other colleges.

Conclusion

The new engineering practice component seem to address the chief capability of instilling the skills of part integration, and testing, and deployment in real world. By mastering these skills, the students have, to a great extent, indirectly addressed ABET outcomes (b), (c), (d), (g), and (h). The engagement of students in such complementary practical tasks have increased their confidence in (1) taking part of a large project that requires capacities and capabilities beyond their own, (2) communicating and working in teams to resolve conflicts and conclude projects, and (3) working with realistic constraints and accurately assessing the impacts of a project. It is worth mentioning that many of the students who participated this project are currently employed. Graduates and employers alike feel positively about the new experience and its impact on the engineering practice component of the curriculum.

Acknowledgment

The authors thank the anonymous referees whose comments have improved the quality of this paper. The Authors also thank Dr. Ayaz Arshad, Dr. Raed Mesleh, and Dr. Ismail Ben Mabrouk for their support throughout the duration of the project; Mr. Zahoor Ahmad and Mr. Muhammad Ammad-uddin for providing the technical support; and Tabuk province authorities as well as the Cities of Haql and Sharma Coast Guard. The authors appreciate the guidance and financial sponsorship for the projects by the College of Engineering and SNCS Research Center.

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Appendix A – Student Outcome Evaluation Template

Form 1 – Student Outcome Evaluation

Student Code	Year	Semester

	Student Outcome	Student	Committee	Aggregate
(a)	an ability to apply knowledge of mathematics, science, and engineering			
(b)	an ability to design and conduct experiments, as well as to analyze and interpret data			
(c)	an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability			
(d)	an ability to function on multidisciplinary teams			
(e)	an ability to identify, formulate, and solve engineering problems			
(f)	an understanding of professional and ethical responsibility			
(g)	an ability to communicate effectively			
(h)	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context			
(i)	a recognition of the need for, and an ability to engage in life-long learning			
(j)	a knowledge of contemporary issues			
(k)	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.			

Signature Signature Signature Signature Date

Guidelines:	***Low:*** exhibited no understanding of the matter and provided no supporting evidence ***Medium:*** exhibited some understanding and provided some evidence ***High:*** exhibited deep understanding and provided strong evidence

Appendix B – Project Constraints and Considerations Evaluation Template

Form 2 – Project Constraints and Considerations

Student Code	Year	Semester

ABET Student Outcome		Evaluation 1(low), 2, 3(medium), 4, 5(high)			
		Student	Instructor	Committee	Aggregate
(a)	Economic				
(b)	Environmental				
(c)	Social				
(d)	Cultural				
(e)	Health and Safety				
(f)	Technological				
(g)	Political				
(h)	Ethical				
(i)	Manufacturability				
(j)	Assemblability				
(k)	Aesthetics				
(l)	Ergonomics				
				Overall Evaluation	

Comments:

Signature   Signature   Signature   Signature   Date

Guidelines:	***Low:*** exhibited no understanding of the matter and provided no supporting evidence ***Medium:*** exhibited some understanding and provided some evidence ***High:*** exhibited deep understanding and provided strong evidence