



Infusing Engineering Practice into the Core to Meet the Needs of a Knowledge-based Economy

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Abstract

A number of Middle Eastern countries are experiencing extraordinary rates of growth and development. Concurrently, they have been placing an increasing focus on building sustainable, knowledge-based economies. To function in such economies, professional engineers require not only technological know-how, but also a set of key professional skills and broad understanding of contemporary issues. Critical to efforts to prepare local engineering undergraduates for careers in today's economy, it is argued, is a rethinking of how engineers are educated. In this paper, the major aspects of calls for reform are highlighted, with a discussion of suggested pedagogical approaches and changes in learning environment that can better prepare engineers for the roles they will play in the 21st century. One set of innovations which appears to be having positive impacts in this direction are the efforts of the Arts and Science Program at a small Middle Eastern engineering university. The A&S Program provides the core courses in the first two years of engineering studies at this institute. Over the past two years, it has been designing and implementing a comprehensive set of curricular innovations in order to better prepare local engineering undergraduates for engineering studies and careers in the energy sector. Three components of this comprehensive approach will be presented in this paper, with reference to how each was conceived, designed, and implemented. Early indications of the impacts are also shared. The paper will conclude with identifications of challenges faced and recommendations for how to better enable and support continuing enhancement of the preparation of engineering students for the 21st century.

Introduction

Today's global economy is fueled by rapid innovation and technological breakthroughs. The impacts of these changes and their contribution to development are perhaps no more evident than in the countries of the Middle East, where cities such as Abu Dhabi, Dubai, Doha and Kuwait City have witnessed miraculous transformations over the past decade. In the United Arab Emirates (UAE), national leaders are concurrently calling for movement towards a sustainable, knowledge-based economy, with an emphasis on developing engineers and scientists from within the local population: "Now that the infrastructure is in place, the education focus is on devising and implementing a strategy that will ensure the youth of the country are ready to meet the challenges of the 21st century workplace."¹, p. 226

That local calls for increased interest in engineering in the UAE are being heard is evident in recent statistics. The number of students enrolled in engineering degree programs in the UAE has risen from 7,828 in the academic year 2008-9 to 10,783 in 2011-12, a 38% increase in just three years.⁷ Concurrently, there has been a dramatic increase in the number of higher education institutes offering degrees in engineering, from fewer than five in 2001 to more than 20 of the 77 licensed institutions of higher education offering engineering degrees in 2012. It is vital that once enrolled, these students persist in their engineering programs as well as in the field after graduation. The engineering curricula, what is taught, and how it is delivered are key to both retaining students and developing in them the wide range of skills and knowledge needed in a globalized economy. In many ways the type of engineering education available in the country will determine the degree to which the ambitious goals being set will be realized.

To function in the 21st century workplace, engineers require a full set of professional skills in addition to technological know-how. The effective engineer in industry is one who has excellent interpersonal skills, is able to work on multi-disciplinary teams, possesses a broad knowledge base, is aware of global issues, possesses information and leadership skills, can communicate both orally and in writing, is creative, and has the skills and knowledge to bring about innovation, all while understanding business and legal aspects of professional practice.^{2, 3, 4, 5, 6}

Traditional engineering curricula and courses have struggled to address outcomes related to these skills, often working with the assumption that students either enter their programs with the skills, or will acquire them with little explicit instruction or assessment. This was the situation at the university discussed in this paper prior to the initiation of changes within the Arts and Sciences Program, a process that began in fall 2010. First, the theories behind the curricular and pedagogical reforms being implemented are discussed. This is followed by presentation of selected components of the efforts of the Arts and Sciences Program at a small Middle Eastern engineering university currently in the process of implementing innovations in order to better prepare undergraduates for engineering studies and future careers in the energy sector. The paper will finish with a brief discussion of the challenges faced and recommended means for supporting further innovation.

Engineering Education: Past, Present and Future

Up until the 1950s, university engineering faculty were primarily drawn from practitioners of engineering, with engineering education curricula based largely on engineering practices and preparation for practice. In focusing on the practice of engineering, personal, interpersonal and systems building skills were naturally a part of what was learned. The focus of engineering education began to shift in the 1950s following the publication of the Grinter Report.⁸ Based on this report, engineering schools moved towards a more scientifically oriented curriculum that emphasized mathematics, chemistry and physics through a core set of six engineering sciences, ignoring concurrent calls to continue to include professional and social responsibilities in the curriculum. Over time, as older faculty retired, engineering faculty and curricula became ever more focused on a scientifically based engineering curriculum, mostly at the expense of other aspects of professional engineering such as design and professional skills. Today, engineering schools are mostly populated by engineering researchers who are less familiar, and less comfortable, with a curriculum that integrates theory and practice, and who have little if any industrial experience. The result is a focus on specialized disciplinary knowledge that emphasizes the fundamentals of engineering, with little space for the development of professional skills or a broader understanding of what it means to be an engineer and the role of engineering in society.

The current state of engineering education has led to numerous publications calling for reform. These include titles such as *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*⁹, *Re-engineering Engineering Education in Europe*¹⁰, *Rethinking Engineering Education: The CDIO Approach*¹¹, *The 21st Century Engineer: A Proposal for Engineering Education Reform*¹², *Educating Engineers: Designing for the Future of the Field*¹³, and *Holistic Engineering: Beyond Technology*¹⁴. In the United Arab Emirates, the aim of on-going education sector reform is "...to ensure that graduates have the skills and qualifications to drive economic growth."^{15, p. 96} As the K-12 education sector, industry and engineering practice continue to

evolve, engineering education should, it can be argued, also be transforming. However, the rate of change in engineering education practices has mostly lagged behind those of industry and K-12 STEM education systems, not only in the UAE, but worldwide. Before looking at how we are attempting to address this issue for our specific institute, we first discuss the background philosophy that serves as a foundation of our efforts.

Initiating Innovation

As a program we have approached the redesign of our curriculum through a process similar to that outlined by Kerns, Miller, & Kerns.¹⁶ This involves four stages beginning with a discovery phase that, in turn, leads to invention, development and testing phases. Part of the overall discovery phase was a reading and discussion of various chapters from the publications listed above during a series of faculty workshops held in spring and fall 2010. Discovery continued with an examination of pedagogical approaches and learning environments that could support achievement of the desired student learning outcomes, visits to partner universities, and small scale pilots in individual classrooms.

Pedagogical approaches and learning environments From a classroom teaching perspective, the called-for reforms studied suggest moving away from teacher-centered lectures to learning environments that actively engage students with discussion of, and critical thinking about, economic, ecological and social issues. Claudio Borri, writing in the foreword to *Re-engineering Engineering Education in Europe*,¹⁷ states that a significant outcome of reform efforts in Europe “will be a move towards student-centered higher education and away from teacher driven provision” (p. 7). This philosophy is intended to serve as an integral component of our efforts. Key practices that encourage desired student and faculty behaviors include inquiry-based learning, just-in-time teaching, problem-based discussion, cooperative learning, hands-on projects, critical reading, and student writing and presentations. No longer is learning only the material presented by the course instructor considered sufficient; there is simply too much to cover. Rather, we approach our reform efforts from the perspective that students need to learn how to learn – and how to think and act like engineers. Such an approach requires that students hear the same message in all of their core courses. Thus we are aiming to move all core program courses away from traditional lecture and exams, towards teaching and learning that is *process* oriented, sets high expectations for students, and provides the support that enables them to achieve those goals. This means emphasizing both formative assessment, which aims to help the process of skills and positive attitude development, and summative assessments, which measure the level of student development in an area at a given point in time.

A key factor in the success of these pedagogical approaches is a basis in rigorous research in the field of learning sciences. The National Research Council’s seminal publication *How People Learn: Brain, Mind, Experience, and School*¹⁸ summarizes much of this research. Chapters from this document served as another key piece of background reading at the beginning of our reform efforts. Evidenced-based concepts promoted include three core components that faculty are asked to consider when seeking to innovate classroom practices for impact. The first component is the necessity of engaging students’ prior understandings. Traditional, lecture-based approaches to engineering education often view the instructor as the source of all knowledge, and students as the empty vessel into which this knowledge can be poured. The reality is that all students enter every classroom with preconceived notions of how the world works. The

engagement of these preconceptions helps to better prepare students for new concepts. Second, there is an essential role of factual knowledge and conceptual frameworks, and it is vital that faculty work collaboratively to identify the organizing concepts for their discipline. Understanding of facts within a clearly articulated framework facilitates both retrieval and application of the knowledge. Finally, there is a necessity for self-monitoring during the learning process. Learning is enhanced when faculty provide opportunities for, and the needed scaffolding to enable, students to take a metacognitive approach to learning, meaning reflection on the learning process, discussion of the degree to which clearly stated and shared learning objectives have been obtained, and opportunities to identify where misunderstanding remains. In this way, a portion of the responsibility for learning is transferred to the student, making them “an active agent in acquiring knowledge and skills.”^{18, p. 1}

Learning Environments The pedagogies described above have to a large degree become part of what is valued and practiced at our institute, as in educational settings worldwide. They began with the efforts of the early adopters, those who have a passion for teaching, and now happen routinely at the level of an individual instructor across many core courses. However, at our institute, similar to what is reported in the *Innovation with Impact* study, “...most of these pedagogies are being employed in long-standing environments, namely laboratories, research, or internships...”^{19, p.33}. To promote a more widespread implementation across the departments in our program we sought to bring about changes at a broader curricular level and to introduce these pedagogies into regular classroom practice. Research has shown that for young adults, such the desired skills and dispositions are best learned through experiential approaches (Cohen, 1996; Kolb, 1984).^{20, 21} We therefore have begun to implement them in a variety of ways as part of an overarching comprehensive approach to developing in students the needed academic and professional skills, and technical know-how, through exposure to what it means to be an engineer.

Implementing Change in the Core

Offering degrees only in engineering, the university at which the below innovations are taking place has an annual enrollment of just over 1200 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 government high schools which have primarily promoted a concept of learning through memorization. Curricular innovation within the Arts and Sciences Program, which offers courses in the first two years of the undergraduate engineering programs, was initiated in spring 2010 in response to identified needs within our student population, and as part of the broader discussions taking place within ABET accreditation and institutional strategic planning efforts. Our 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 skills, and professional skills such as project management, team-work and communication. The overall comprehensive package of approaches is being implemented across several different structures. The package includes 1) the introduction of a studio approach to teaching physics, 2) redesign of a freshman engineering seminar, 3) a substantial expansion of academic support services, 4) a two semester project-based Communications course sequence, and 5) a multidisciplinary sophomore level

cornerstone design course, which includes annual participation in an international design competition. The conception, design, and implementation of the first three are discussed below.

Studio Physics The early pioneer in innovation has been our calculus-based, introductory Physics course. The Physics Department was inspired by new instructional models referred to in the literature as ‘Physics by Inquiry’, ‘Workshop Physics’, and ‘Studio Physics’. The adopted “hybrid-studio” approach is a shift in orientation of teachers and students to increase student engagement and motivation and to thereby improve student retention, learning and achievement.^{22, 23} The studio approach entails a switch from a traditional lecture/lab format to a curriculum that aims to maximize student engagement and improve learning outcomes via more natural, student-centered instruction with greater emphasis on course accessibility, learner feedback, elements of inquiry, and the resolution of misconceptions.

In the fall of 2011, a single section of 18 female students were treated to a first trial of the Studio Physics approach for Physics 1 (Mechanics). The initial success led to expansion of the pilot to involve two female sections (with a total of 40 students) the next semester, and in Fall 2012, the reform finally extended to all Physics 1 sections (while still totaling only 35 male and 17 female students). For the purpose of assessing impacts, data from the Studio Physics sections (S) is compared with data from students enrolled in traditional lecture/laboratory sections (T). Data from traditional sections is included for semesters starting from Spring 2009 (Sp09) to Spring 2012 (Sp12), after which Physics 1 was no longer taught in a traditional format in any sections. A chart of the number of students in each of these groups is shown in Figure 1.

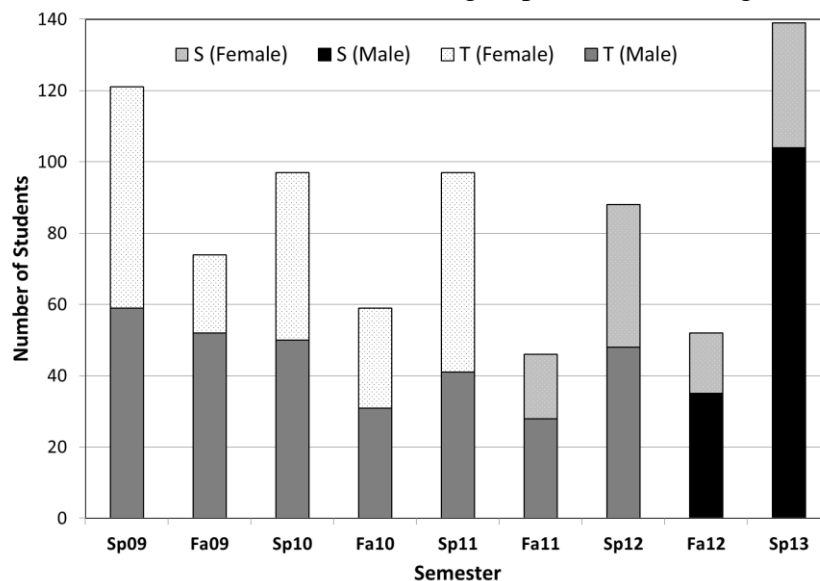


Figure 1: Number of students enrolled in studio and traditional course sections during Spring (Sp) and Fall (Fa) semesters from Spring 2009 (Sp09). The chart indicates the growth in the number of students participating in Studio Physics at the PI, from fewer than 20 female students in Fall 2011 to nearly 140 in Spring 2013.

The main change in approach is that a coherent system of Studio Physics student group activities that fully integrate the theoretical and practical aspects of the course’s content with other developmental learning objectives has replaced the traditional lecture and lab components. These additional objectives include the promotion of student learning habits such as preparation

for class, note-taking, documentation and organization of work, and time management, all of which are assessed through authentic formative tools. In addition, new content has been added to support a far stronger emphasis on measurement uncertainties in the course. Approximately 2/3 of the total available class time is now dedicated to student group activities. Because of these new objectives and the over-arching goal of creating a more supportive and effective student-centered learning environment, studio activities have replaced the traditional formal laboratory and some of the course lecture time. The typical weekly schedule is shown in Figure 2.



Figure 2: A typical Studio Physics schedule, indicating the significant time commitment to student activities and the two lecture days that start and finish each week.

Students spend three days per week doing studio activities (two 75 minutes and one 50 minutes), rather than just one 3 hour lab per week. Also, teachers and students stay together for the full schedule of lectures and activities. These changes directly counter a functional 'disconnect' that existed between lab and lecture due to timing (lab sections meeting on different days during the week) and teaching practices (different lab sections led by different teachers or lab staff). The new semester schedule consists of approximately forty distinct studio activities (rather than the 10 labs in the previous format).

All class activities are conducted in groups of three (and rarely, two or four) students. Heterogeneous groups are formed by the instructor, initially based on student grade-point averages and later by student performance on course assessments. As students work together, they discuss and debate the details as they work to complete activity tasks, particularly since each individual is responsible for writing out answers, explanations, and solutions along the way. These conversations are one of the main purposes of the studio approach.



Figure 3: Students in a group using individual notebooks to work out the details of assigned activity tasks.

The impacts of the studio approach have been measured via a combination of quantitative and qualitative instruments including a comparison of student course success rates, student performance on common examinations, a student survey focusing on the studio approach, and

comparative student gains on the Force Concept Inventory. The initial results of this curricular reform are encouraging.

In exit interviews student comments regularly indicate that learning of both content and professional skills through exposure to what it means to be an engineer is occurring:

[In our high-school physics courses] we used to work individually and then there were just some labs... that were not related to what we were doing theoretically. It was frightening for us... [Now, in studio] it actually simulates what engineers do. We work in teams; we collaborate with each other in order to get the work done. Now, we find it enjoyable to take physics; we are sharing our experiences and correcting each other's mistakes. It's a science course but it has actually improved our social relationships.

Quantitative measures are also positive, though interpretation of results is complicated by a number of factors. First, as shown in Figure 1, we have small student numbers and class variability due to fluctuations in university student recruitment and enrollment. Related to this, there are variations in student preparation and background. Also, since the Physics Department's practice is to use new (or edited) free-response problems/questions for tests and exams, additional fluctuations are introduced into measures of student performance. These issues should be kept in mind in the following analysis and discussion.

Since the dominant assessment in Physics 1 remains the final exam, we start with it to look for evidence of learning gains in terms of technical know-how attributable to course reforms. While there are variations, we generally see the trend observable in Figure 4, with students from both traditional and studio approaches performing better on early questions and a bit worse on the later questions. Shown by the grey bars in the figure, the average score is obtained from all of the sections taught in the traditional manner between Spring 2009 and Fall 2012 (involving 524

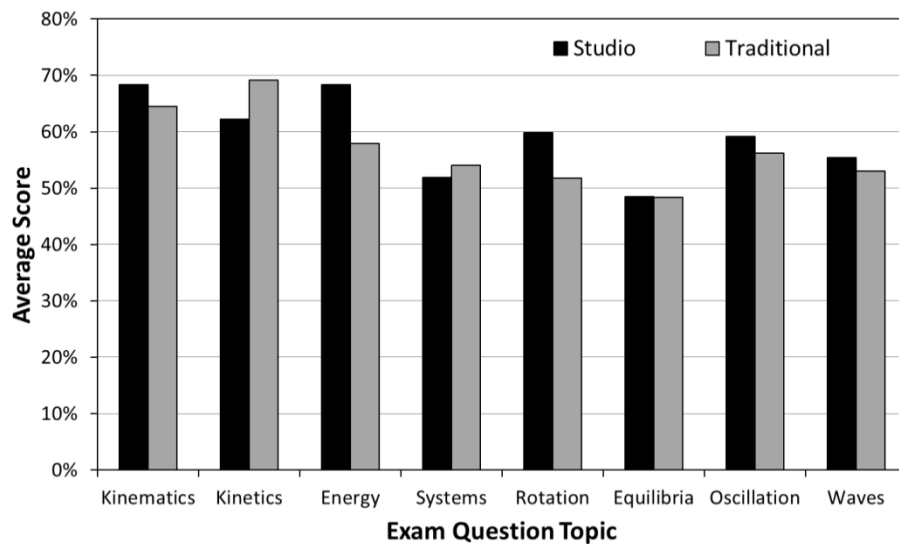


Figure 4: Average scores on final exam questions labeled by topic, comparing student performance in studio and traditional sections, using exam data from Spring 2009 to Fall 2012. Score averages were obtained from either 110 or 524 students in the studio or traditional groups, respectively.

students in all). This is compared with averaged scores from studio physics sections between Fall 2011 and Spring 2012 (involving 110 students). Looking at the figure, the most conservative interpretation is that, at least, the change in course format has not done the students any significant harm in terms of learning Physics. However, looking at the trends in more detail provides a more encouraging comparison. For six of the eight topics, the studio group's performance is the same or somewhat better than the traditional group's.

Another concern in interpreting the above exam results is the fact that the first two pilot semesters of Studio Physics involved only female students, while the results in Figure 4 are showing averages of all sections, irrespective of gender. Is the small apparent gain attributed to the studio reforms actually only a gender difference? To explore this, the same data from Figure 4 is examined with student and traditional student groups further segregated by gender.

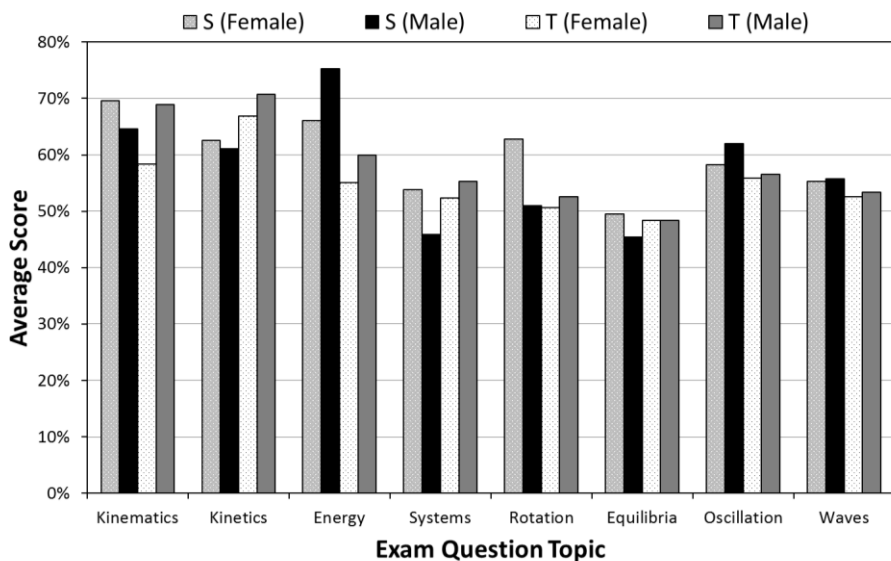


Figure 5: Average scores on final exam questions labeled by topic, comparing male and female student performance in studio and traditional sections, using exam data from Spring 2009 to Fall 2012. Score averages were obtained from 75 female and 35 male students in the studio group and 215 female and 309 male students in the traditional group.

Looking at the two rightmost bars for each topic, we can compare the performance of female and male students in traditional sections. Figure 5 shows that, on average, female students tend to do a bit worse than males for the early topics and then gradually they catch up. The difference tapers from a surprisingly large 10% on the first topic to a negligible value by the fifth topic, rotation. While the source of this difference is not known, it is clear that there is some initial disadvantage faced by the female students relative to the male students in the traditional groups. This may be a result of the high school education they have received. In contrast, by looking at the two leftmost bars for each topic, we can compare the performance of female and males students in the studio sections. While the statistical variations are more pronounced here due to smaller numbers of students, the female disadvantage with the early topics is no longer apparent. In fact, in the studio sections, the question averages for female students are higher than for male students on five of the first six exam topics. Comparing averages for male students in studio vs. traditional groups, it appears that generally the performance is about the same, with two topics showing apparent positive gains (energy and oscillation) balanced out by apparent declines

(particularly the kinetics and systems items). So, there does appear to be a gender difference in terms of impact. A close examination of Figure 5 suggests that male students have no clear aggregate gain or loss from the reform but that female students are showing positive learning gains. It appears that this may be the significant learning gain that is attributable to the switch from the traditional to the studio approach.

Along with the strikingly positive student attitudes that are revealed by surveys and exit interviews, there may be a more important and quite dramatic consequence: students are no longer withdrawing from the course at significant rates. The trend is illustrated clearly in Figure 6, showing the sharp decline in student withdrawal from Physics 1 during Fall 2011 and Fall 2012. In particular, by comparing 2007-2009 with 2012, the biggest change in this DFW chart is the decrease in the W outcomes. Clearly, the overall grading distribution (as shown here by the fractions of D and F grades) has not changed very significantly.

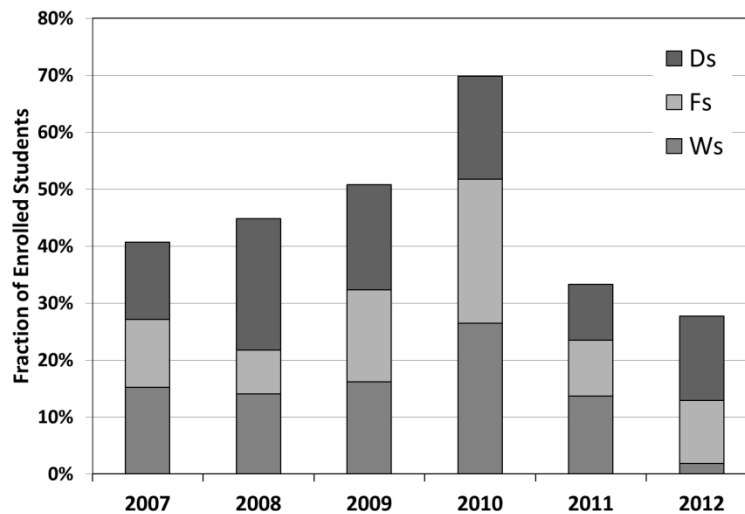


Figure 6: DFW rates for students' withdrawing (W) or getting a grade of D or F in Physics 1 during Fall semesters in recent years. The dramatic 2009-2010 rise in DFW rates is generally attributed to declining standards of student preparation prior to enrollment in Physics 1.

The early indications are that the ongoing curricular reform of Physics 1 has already achieved a significant positive impact on student attitudes and opportunities to experience what it means to be an engineer in terms of working as a team to solve authentic problems. It is also starting to show evidence of improved student learning and achievement. More importantly, students are developing interpersonal, communications and academic skills that will serve them well in other courses and in their future career as an engineer. While the studio physics initiative is furthest along of our new innovations, it is not alone. As mentioned earlier, there are several integrated efforts. A second component is the Freshman Engineering Seminar.

Freshman Engineering Seminar Traditionally at our institute this course was conducted in a large lecture hall and focused mainly on exposure to the five degree programs and future employers through a series of teacher-centered lectures and guest speakers. It was intended to provide students with the information to make a mature and informed decision on their choice of major along with receiving factual information about being a university student and where to get assistance when needed. As with other initiatives, changes in this course

began through a discovery phase, with a substantial focus on how to infuse a variety of professional skills and an engineering experience into the course, including such items as multidisciplinary teamwork, life-long learning, and thinking skills. One of the first “inventions” was to create multiple break-out sections of 15 – 20 students so that the content could be experienced through more student-centered, hands-on approaches. This course now aims to provide an opportunity for students to engage in learning experiences that will enhance their success both in undergraduate studies and in the work place after graduation. Emphasis is placed on the development of skills, attitudes and practical knowledge that will enable the student to reach his/her short and long-term academic goals through experiencing what it means to be an engineer. The student learning outcomes include that the student will have

1. Demonstrated an ability to manage a small project;
2. Worked successfully as part of a team to complete assigned tasks;
3. Evaluated decisions or actions based on a discussed code of ethics;
4. Critically discussed the role of engineering and science in advancing and supporting global and social solutions in an economically and environmentally sustainable manner;
5. Described the jobs and activities typically performed by mechanical, electrical, petroleum, and/or chemical engineers and geoscientist in the petroleum industry.

Additional specific course learning objectives focus on measurable means of assessing thinking skills and life-long learning. The level of student attainment of the above outcomes is measured through a series of formative assessments during classroom activities, written assignments and presentations. Overall achievement levels across all sections is evaluated through an annual course assessment. This data is then combined with data from the other courses to determine the degree to which A&S Program learning outcomes are being achieved. Baseline data was gathered in Fall 2010 through a combination of the course portfolio data, engineering faculty surveys, and student surveys. Data from Fall 2012, during which all reforms were in place, has been gathered and is being analyzed during Spring 2013. Early indications are that while not having as large an impact as the studio Physics described above, they are positive.

Academic Support Structures Given the fact that the majority of our students are first generation and that they are coming from high schools that primarily promote learning through memorization, a large percentage are underprepared for university studies. In order to enhance retention and enable all students to reach their potential, our comprehensive approach to developing technical know-how and academic and professional skills through exposure to what it means to be an engineer also includes an integrated academic support structure. This consists of 1) placement tests in mathematics and science for all newly matriculated students, 2) developmental courses, 3) supplementary hours for introductory Physics and Chemistry, 4) a comprehensive program of tutorials and student success workshops, and 5) an Academic Intervention and Mentorship (AIM) program for academically at-risk students. These structures were developed by a core group of people from our academic programs, counseling office, IT and Student Affairs. They worked together to “invent” new support structures and integrate existing components. The overall structure was implemented in fall 2012 and continues to be

developed. A brief description of key aspects of these structures is presented below, followed by initial evaluation data showing positive impacts.

First, in fall 2012 we began to offer Developmental Courses. These courses provide a comprehensive process that addresses the intellectual, social, and emotional growth and development of a student. Our developmental courses focus on ensuring academic preparedness in the given discipline, enhancing the skills and attitudes necessary for the attainment of academic, career and life goals, and promoting acquisition of the competencies needed for success in academic coursework. These courses are non-degree, and are taken prior to Calculus 1, Chemistry 1 and Physics 1. Placement into the developmental courses is based on student performance on mathematics and science placement exams. Students performing above the cut-off for developmental course enrollment, but who would still require additional support while enrolled in the introductory degree course, are provided with supplementary hours, two per week, for Chemistry 1 and Physics 1. These are taken concurrently with the relevant course. Supplementary hours provide structured learning support for targeted students. Activities include facilitated problem solving, study skills development, and use of additional resources to enhance understanding of the material being presented in the regular course. Students also receive regular focused feedback on their development as a learner. Students who are identified as academically at risk in two or more core courses are enrolled in the Academic Intervention and Mentorship (AIM) Program.

The AIM program brings together faculty, advisors, counsellors and Student Affairs to offer students the best opportunity to succeed. The AIM program is designed to provide an enhanced support structure for students who have been identified as academically at-risk in two or more subjects. For such students in A&S, participation in the AIM program is mandatory. The student is required to sign a negotiated contract indicating the steps that will be taken to remedy identified issues. The students are expected to meet with an AIM advisor at least once a week to discuss their classroom performance. The students are required to attend relevant tutorials if they are not already taking the supplementary hours. In addition, over the course of every semester, success workshops are run for all students, but are required for AIM students. Attendance at the department-run tutorial centers and the relevant Student Affairs-run success workshops is mandatory for AIM students. Typical workshops include:

- Time Management
- Study Skills
- College Survival
- How to study Chemistry, Math and Physics
- Positive Habits

The AIM program was first implemented in fall 2012; thus initial statistics serve only as a guide to how successful the program is and could be. Roughly 20% of core students were referred to the program, meaning that they were struggling academically in two or more courses. The numbers of male and female AIM students is consistent with the ratio of males to females university-wide. Of the students served in the program 47% of female AIM students went on to pass all courses, with 33% of male students doing likewise. All supported students completed the

semester. Although it is impossible to say definitively how much affect the program had, these results are encouraging and exceed the success rates of previous years.

Conclusions

Overall, we have and will continue to assess the impacts of implemented innovations in terms of meeting enrollment targets during a period of increased competition for a limited pool of potential students, and retention of those students who are admitted to our university. For courses such as the Studio Physics, Communications, Cornerstone Design, and Freshman Engineering Seminar, impacts within the classroom are studied through quantitative data such as DFW rates, student academic achievement in the content area, and documented achievement levels of professional skills learning outcomes, primarily through formative assessments. In addition, qualitative and quantitative feedback on student achievement of outcomes continues to be gathered from A&S students, A&S faculty, and engineering program faculty, and will be compared with baseline data gathered in 2010.

Implementation of the innovations described above enables the engineering education we are providing to move away from the linear approach of many engineering curricula to a spiraling curriculum in which students experience what it means to be an engineer right from the beginning of their studies, and where the connections between theory and practice become more evident. Such programs aid in developing engineers who are not only technically competent, but who are also problem solvers, team players, entrepreneurs, and globally-aware critical and creative thinkers; in other words, these programs are a means to “enrich and broaden engineering education so that those technically grounded graduates will be better prepared to work in a constantly changing global economy.”^{9, p.1}

Downey and Lucena²⁴ have argued that ultimately, there could be multiple engineering tracks, for example engineering sciences, engineering management, and an engineering public policy tract. Given the movement in the Middle East toward knowledge-based societies, and the probability that engineering graduates will play leading roles in government and industry, a more liberalized version of engineering education is certainly worth considering. The Middle East is at the fore of much of the growth in today’s global economy, and engineers have an important role to play in leading the efforts to achieve sustainable, knowledge-based economies. The field of engineering can and should be a major contributor to these efforts, ensuring that the engineers of the 21st century possess much more than technical knowledge. They will need to understand the impacts of engineering on society and possess a wide range of professional skills. To develop such engineers, widespread transformation of the current approaches to engineering education will be required at both in terms of pedagogical approaches, learning environments and overall curriculum. As described in this paper, the A&S core program at our institute is making efforts to innovate and transform engineering education, and the data indicate that we are having demonstrated positive impacts, yet change is happening at a slow pace, and, despite efforts at a comprehensive approach, continues to occur to a much greater extent in some departments than in others. Early efforts to include Mathematics and Chemistry Departments in these innovations have met with resistance, and only limited changes have occurred. To bring about more expansive reform will require commitment from all faculty, department chairs, program directors and even the university provost.

From the bottom up – innovations initiated by individual faculty or small groups of faculty – can come ideas, skills, and knowledge adapted to local needs and conditions. From the top should come guidance, accountability, resources, incentives, and networking. A hybrid approach that draws on the strengths of both top-down and bottom-up initiatives can build a collaborative partnership for engineering education innovations with impact. Such innovation is vital if engineers are to assume a larger role in shaping society. As the trend towards more sustainable, knowledge-based economies continues, engineering practice will continue to evolve, and so should engineering education, for “in the 21st century, an ever-increasing need will emerge for a holistic breed of engineer – one who can work across borders, cultural boundaries, and social contexts and who can work effectively with non-engineers.”¹², p. 67

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