A Global Collaborative Effort to Enhance Design in a Mechanical Engineering Curriculum in Saudi Arabia

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A GLOBAL COLLABORATIVE EFFORT TO ENHANCE DESIGN IN A MECHANICAL ENGINEERING CURRICULUM IN SAUDI ARABIA

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ABSTRACT

In 2008, King Fahd University of Petroleum and Minerals (KFUPM) in Saudi Arabia and the Massachusetts Institute of Technology (MIT) partnered together to develop project-based curricular material to be tested out in a new undergraduate course offering in KFUPM's Department of Mechanical Engineering. This paper details some of the unique challenges to collaborating across countries and time zones, and the approaches the KFUPM-MIT team used to address these. These approaches have so far included the establishment of a shared vision for the project and the use of an array of technologies to facilitate distance communication. The paper concludes with a description of lessons learned that might be useful for future programs that plan to engage in international collaboration on design education.

INTRODUCTION

King Fahd University of Petroleum and Minerals (KFUPM) is a leading technological university in Saudi Arabia that is responsible for graduating a large number of the country's top engineers. In an effort to continuously improve their undergraduate engineering education program with respect to engineering and product design, the Department of Mechanical Engineering launched an effort to benchmark programs at comparable institutions and use this knowledge to renovate existing design-related courses in their undergraduate curriculum. The need to improve the design content of courses in the Mechanical Engineering Department was also expressed by alumni and their employers in response to a questionnaire on their views on the undergraduate program.

The Massachusetts Institute of Technology (MIT) was chosen to be a partner in this collaborative effort to develop project-based curricular material, in part because of its experience in offering a range of hands on, project-based design courses in mechanical engineering at all levels of the undergraduate experience. Example MIT courses in the area include the senior capstone design course, *2.009 Product Engineering Processes* [1] and graduate level courses in product development, *2.739J Product Design and Development* [2] and *ESD.40 Product Design and Development* [3].

In total, six faculty from the KFUPM Department of Mechanical Engineering and four faculty from Mechanical Engineering at MIT collaborated on this project. This collaboration took place under the auspices of the KFUPM-MIT Center for Clean Water and Clean Energy, a new joint center promoting research and teaching collaboration between the two institutions.

A set of explicit goals were formulated collaboratively by the two institutions at the outset of the project. These goals include:

- To develop a culture of design education in the Mechanical Engineering Department at KFUPM
- To identify priorities for best serving the educational needs of students at KFUPM with respect to design
- To evaluate best practices in design education
- To develop material for a sophomore design course
- To evaluate and revise senior design project courses
- Enhance design components within the existing Mechanical Engineering curriculum

In order to come up with a common vision and set the above mentioned project objectives, an extensive benchmarking study of similar US and European institutions was performed. The results of ME-KFUPM stakeholder surveys on the need of design in Saudi industry were also utilized to set the objectives of this project.

This paper will focus primarily on one of the key elements of this collaboration, namely the development of a sophomore level design course at KFUPM. KFUPM and MIT worked together to determine educational goals for a sophomore design course at KFUPM, a structure and schedule for the course, topics to be taught, the collaborative development of lecture and lab material and activities, and the creation of a semester long, hands-on design project to serve as the centerpiece of the course itself.

This paper will provide some description of the development of the course, but the emphasis will be on the nature of the collaboration between KFUPM and MIT and the lessons learned from the process. It is believed that focusing on the collaboration aspect of the work will provide insights that might be of relevance to a broader audience. The collaboration between the two institutions was rooted in the work of the project itself, but the use of a range of communications technologies was essential for facilitating the work. More importantly, there was a willingness on the part of both MIT and KFUPM teams to try to create a meaningful design class for KFUPM students.

PHASES OF DEVELOPMENT OF PROJECT-BASED CURRICULA

The development of project-based curricula took place over several phases, described in detail below. It began with an information gathering phase that involved surveying existing design programs as well as alumni of KFUPM, and culminated in the planning and design of a sophomore-level design course to be offered at KFUPM.

Phase 1: Benchmarking design curricula

Benchmarking was conducted to observe how design is taught elsewhere. To evaluate the global status of engineering design education, the team performed benchmarking by analyzing mechanical engineering and engineering design curricula in a number of comparable universities from around the world. The gathered information covered the vision, mission, research centers/groups, and all engineering design courses of each institution. All universities appeared to acknowledge that engineering design is a challenging subject to teach and learn. At the same time, they were also convinced that engineering design is personally rewarding and offers the opportunity to make a major impact to the world and to "make jobs, not just have one."

Phase 2: Alumni and Employer Surveys on Design

The KFUPM-MIT project sought to define the design needs of KFUPM graduates by finding out whether design is a highly valued skill-set in engineering graduates in the Kingdom of Saudi Arabia. The responses of major employers of KFUPM graduates to a carefully designed questionnaire were analyzed. The surveys addressed a number of important design skills such as creativity, the ability to solve open ended problems, proficiency in CAD tools, and communication. These engineers were employed mainly in oil, gas and petrochemical, energy production, and saline water desalination based industries. The traditional view of some of these engineers and employers is that the major role of engineers is in construction, operation, and maintenance. At the same time, they may be involved in design modification work of some equipment or systems or interface with designers during the design phase of some of these projects. The majority of employers agreed that design is an important skill-set that they would like to see in their engineers.

KFUPM Mechanical Engineering alumni were also surveyed to assess their degree of satisfaction of the design content in the present curriculum using a similar questionnaire. They also agreed that design is highly valued skill-set in engineering graduates and would like to see enhancement in this area.

The KFUPM-MIT project was further influenced a number of other factors. These include the results of KFUPM stakeholder surveys in 2005 regarding the contents of the Mechanical Engineering program during the KFUPM Mechanical Engineering department self-assessment exercise, input from the department's industrial advisory committee, and ABET recommendations. The Mechanical Engineering department had already made a first revision of the design contents in its curriculum following the self assessment round of 2003-2005. This resulted in the introduction of design projects in a number of courses and the development of a senior design course for the Applied Mechanical Engineering program. A more systematic approach proved necessary after evaluation. The major outcome of the preceding surveys, recommendations and benchmarking results became the impetus for proposing a new sophomore design course and further increasing the design and product development content of the junior and senior level courses in the Mechanical Engineering Department at KFUPM.

Phase 3: Proposed sophomore design course

The proposed sophomore mechanical engineering design course at KFUPM will include the following:

1. Large Lecture Format. It is anticipated that several hundred students will be enrolled in the course, and a large lecture format will permit lecture material to be presented in an efficient manner. One hour lectures will also include short, in-class design-related exercises.
2. Smaller lab sections. Lab sections of approximately 25 students will allow teaching staff to provide personal instruction to the students that would not be possible in the large lecture format. Lab sections will last three hours and will be used primarily as time for students to design and build their projects.

3. Students will go through the experience of product dissection and re-assembly before starting the hands-on project. In this way, they gain familiarity and confidence with tearing down and building physical assemblies.
4. The centerpiece of the course will be a common design project that will start in the first or second week of the course.
5. Kits of materials to be used in the design project will be distributed to students. Students will be expected to fabricate simple critical components in a designated lab space.
6. Students will work on the projects in groups of 4 to 5 individuals.
7. Each team will be supported by one senior student mentor who has received training and is familiar with the project. It should be noted that this will be the first such experience in KFUPM.
8. Projects will be presented at the end of the course in a competition that will take place outdoors on campus.

The design project brief will be to design and build a device that is positioned roughly 5 stories high in the air that will launch an egg so that it lands intact in the center of a target positioned below on the ground, while constructing the lowest cost design that reaches the ground in the shortest amount of time. Progress on the design project will be assessed at milestones throughout the semester.

The devices will be made from materials provided in a kit (Figure 1) given to each team of students (assume 4 students per team). Materials in the kit will have assigned costs, so the students can compute the cost of their design (see also note at start of the proposed kit contents section below). The kit includes readily available, relatively inexpensive materials that can be incorporated into a design in a number of ways and can be easily fabricated and assembled, such as foamcore, plastic water bottles, and aluminum sheet.

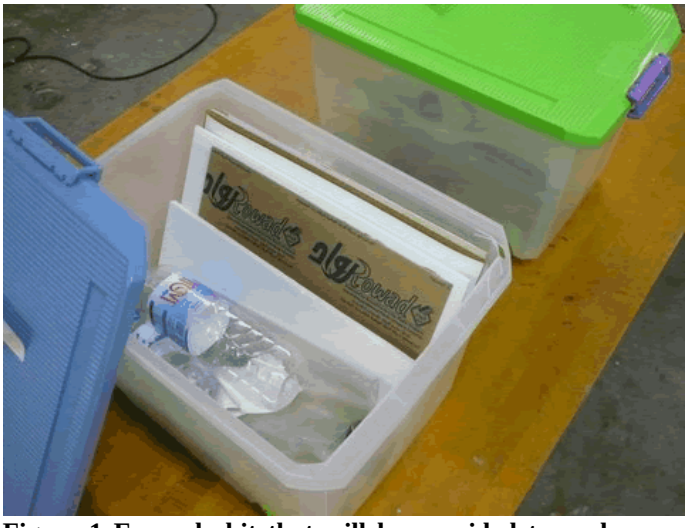

Figure 1 Example kit that will be provided to sophomore design students

The students will be graded through their notebooks, project milestones, homework exercises, and final presentation that guide them to a successful prototype at the final competition.

CHALLENGES OF KFUPM-MIT COLLABORATION

The main challenges in collaboration on the KFUPM undergraduate design program may be divided into two broad categories: 1) establishing and maintaining a shared vision of the new design curriculum, and 2) addressing the logistical considerations of collaborating between countries and across time zones.

Establishing a shared vision for the curriculum

In any team project, it is essential to formulate a shared, common goal that all team members can embrace and work towards [4]. One of the keys to the KFUPM and MIT project has been to generate an agreed upon set of goals with a shared understanding of what is meant by a "design curriculum." KFUPM and MIT share many similarities, including their form as institutions that teach and do research primarily on technology. Not surprisingly, however, each school has developed over time particular cultures and norms with respect to the way courses are conceived and taught.

Underlying the explicit goals described in the Introduction section of this paper was a more basic issue that is present any time new approaches are introduced to replace existing ones. In the case of the ME KFUPM curriculum, the concept of a hands-on, project-based design course was somewhat of a departure from the way design had been taught there.

Key departures from the way design had been taught in the Mechanical Engineering at KFUPM in the past include:

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- *Open-ended design projects and design experiences at the Sophomore level*– The benefits of open-ended design projects have been discussed extensively in the literature [5, 6]. Rather than stress written examinations and problem sets, the proposed design curriculum at KFUPM will include design projects to offer students their own opportunity to wrestle with the challenges of generating and implementing a design. These projects will include short, in-class exercises as well as a semester long design project.

- *Team-based design* - In most engineering courses, lectures are aimed at teaching the individual student. However, because of the integrative nature of engineering design, students may particularly benefit from working in teams. Working in groups also tends to simulate how students will operate once they are in they begin in the workforce. In the past, there has not been a strong emphasis on student teamwork in ME KFUPM, so one implicit goal of the KFUPM-MIT collaboration will be to establish an appropriate environment to support it [7].

- *Design projects fabricated by students* – The Department of Mechanical Engineering at KFUPM maintains an extensive machine shop facility that supports both research as well as teaching, particularly in manufacturing. The new proposed design curriculum will center around enabling more direct student participation in design project by introducing design/build/test approach. It will specifically encourage hands-on building by students, under the guidance of the KFUPM faculty and staff, so that they can gain firsthand experience working with materials and fabrication techniques that are essential to understanding and improving their designs. KFUPM has set aside a space within their main machine shop dedicated to the design curriculum that will serve as a laboratory and building space for classes (Figure 2). This space will include workbenches and basic machine tools for prototyping in wood, plastic and metal.

Figure 2 Preparing the sophomore design class laboratory space with KFUPM and MIT faculty and KFUPM students

Logistics of collaboration

The collaboration between MIT and KFUPM involved both synchronous and asynchronous interaction. In particular, synchronous collaboration was challenging because of time differences and differences in the way work weeks are defined in the two countries. The time difference between MIT and KFUPM is 8 hours. This meant that the intersection of work hours between the two institutions was limited to about 3 hours per work day. However, potential meeting times were further constrained by the differences in the nominal work weeks in both countries. The work week in Saudi Arabia runs from Saturday to Wednesday, with the weekends on Thursday and Friday. This is in contrast to the United States where Saturday and Sunday are considered weekend. Thus, video conferences that members of both MIT and KFUPM teams could attend during a normal work day could only take place on a Monday, Tuesday, or Wednesday, provided that each institution's dedicated videoconferencing facilities were available. Because of these limitations on synchronous communication, there was a strong emphasis on asynchronous channels of communication. These communication technologies will be discussed under "Lessons learned."

The above proposed changes meant that many assumptions about design courses had to be carefully rethought by both KFUPM and MIT. In particular, what does it mean to have a project-based course rather than a traditional lecture format? How are students evaluated in a project-based design class? Tests and problem sets are time-tested tools for evaluating student performance. In this new proposed format, design projects and the processes that students follow will be the focus of student evaluation. Both of these measures are somewhat richer measures for student performance, but are also more subjective and require more oversight by teaching staff.

LESSONS LEARNED

A number of lessons have been learned about improving collaboration throughout the course of this project. In a general sense, these lessons address the two categories of challenges outlined in the previous section: establishing a shared vision for the design curriculum, and using technology to reduce the difficulty associated with the logistics of long distance collaboration.

- *Face-to-face meetings are still essential for gelling relationships among team members* – Though the KFUPM and MIT faculty spent a great deal of time and effort to collaborate remotely, meeting and working together in person was key to gaining a better sense of others' work style and motivation. It was invaluable to see the physical space and overall environment of the other university, its culture, and the country. Face-to-face interactions included fairly intensive week-long work periods twice a year. KFUPM faculty would travel to MIT, and then MIT faculty would travel to KFUPM. These intensive periods included a number of meetings and preparation for presentations to other KFUPM-MIT faculty about the project work. In addition to these week-long periods of face-to-face interaction, individual team members from MIT and KFUPM visited the others' campus.

- *Physical immersion in course-building activities* – In the same way that hands-on experience in building is invaluable to students learning about engineering design, it was found that hands-on involvement in building the course was most helpful in learning how to set up a project-based design course. One KFUPM faculty spent over a week at MIT and acted as a member of the MIT teaching team for its senior capstone design course, *2.009 Product Engineering Processes*. He attended lectures, labs, staff meetings, and the final presentations. In this way, he could get a true taste of the course experience. Likewise, one MIT faculty spent a week at KFUPM to gain a better sense of KFUPM educational culture and to work with the KFUPM faculty to discuss hands on design projects and

scout out physical spaces where the final presentations might take place. Finally, members of both the MIT and KFUPM faculty worked together at KFUPM to set up the class laboratory space and procure materials for the "kit" that students would receive for working on their design projects.

To facilitate collaboration and achieve the jointly developed project objectives, the Principal Investigators (PIs) at KFUPM and MIT worked collaboratively to carefully define each task and assign task leaders from each institution. This thoughtful task assignment and continuous interaction between PIs and task leaders has led to a smooth execution of the project thus far.

In lieu of co-located interaction, several communication technologies were employed to facilitate collaboration.

- *Skype:* The PIs have used this communication tool during development of the research proposal and later on to discuss time-sensitive matters.

- *Email*. It is estimated that approximately a thousand messages have been sent between the KFUPM and MIT team and within each institution itself over the course of the project. The emails may contain course material, discussion, exchange of information, or updates on tasks assigned to team members.

- *Video conferencing*. In order to support collaboration between KFUPM and MIT, rooms dedicated for full audio/video conferencing at each institution were constructed. These facilities allow the team members to see each other during the meeting. Regular video conference meetings are held each month. This frequency increases during the preparation the semi-annual meetings and other scheduled events. The agendas for the video conferences tends to be carefully planned and structured ahead of time, and to minimize confusion, discussion was generally led by one person at each university. The material to be discussed is generally uploaded on the wiki (content management system) ahead of the meeting. The minutes of the meeting are usually uploaded right after the meeting. Each videoconference focuses on updates on project progress. Actual project work is usually conducted off-line. Given the limited amount of overlap in work times between the two countries, this style of meeting has been found to be quite effective thus far.

- *Content Management System* – In a distributed project such as this, it is extremely useful to maintain a shared repository for information that all team members can refer to. In this project, a web-based Wiki (Figure 3) was chosen for the content management system because it required only a web browser to access from anywhere in the world, it was relatively familiar to some of the team members, and had a reasonably low learning curve. Initially, the Wiki was hosted by Google Sites. One faculty at MIT took the lead on administering the Wiki so that it stayed organized and updated with the latest information. A single administrator for the Wiki has been effective because of the small size of the KFUPM-MIT team, but probably would not be as scalable for a much larger team.

A screenshot from the KFUPM-MIT design curriculum appears below:

Figure 3 Home page of the KFUPM-MIT design curriculum wiki

The KFUPM-MIT design curriculum Wiki included administrative information, including meeting schedules, meeting minutes, and action items. It also served as a repository for the development of the sophomore design course, including all lecture and lab notes, and accompanying slides. All of these materials were uploaded to the designated space on the wiki. The Wiki managed version control and notified team members when new material had been uploaded. This process of developing materials for the course was highly collaborative, as can be seen in this screenshot from the lecture development stage on the Wiki (Figure 4):

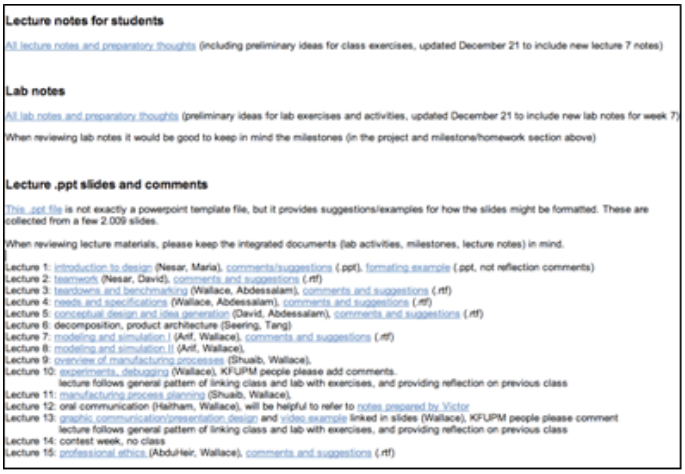

Figure 4 Wiki page showing collaborative development of lecture slides and notes

The KFUPM-MIT design curriculum Wiki was heavily used by all team members, and grew rapidly with the continual uploading of new material. Recently, the Wiki has been migrated to a different MIT-local host in order to accommodate its size. For now, the Wiki works well, although other content management systems such as Share Point may be worth considering in the future.

In summary, the KFUPM-MIT drew on a broad range of means of communication along with a well designed content management system to collaborate with each other. This has reduced many of the challenges associated with the collaborative work of non-collocated teams. However, the sense of many members of the team is that face-to-face meetings remain the most effective, nuanced way to conduct teamwork.

FUTURE WORK

The KFUPM-MIT collaboration has been very successful despite the challenges of working across time zones and cultures. This success may be attributed in part to the commitment of both universities to developing a strong, design-focused curriculum for undergraduates at KFUPM. Practically speaking, this has meant that both MIT and KFUPM have carefully formulated and maintained a shared vision for the project. Furthermore, both MIT and KFUPM have made great efforts to work together in person whenever possible, thus fostering greater understanding of each others' institutions and contexts. Finally, a range of communication technologies have been employed to facilitate communication and collaboration between the two institutions.

One test of the collaboration described in this paper will be the offering of the sophomore design class itself. It is likely that the course will be added to the KFUPM class schedule in the next year.

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