AC 2008-1681: SYSTEMS DESIGN USING REAL-WORLD EXPERIENCES WITH INDUSTRY

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Abstract

The author has co-developed and taught the following courses related to systems design at the author's School of Engineering:

Senior Design Project (3 semester hr)
Manufacturing Related Topics in Probability, Statistics and Reliability (3 semester hr)
Senior Design Seminar (1 semester hr)

These systems design courses taught in a traditional classroom setting meet ABET criteria. However, by adding the non-traditional elective Applied Systems Design with Industry (3 semester hr) to the systems design curriculum, students have been provided an opportunity for a deeper understanding of the need and benefit for systems design and systems engineering methodology.[1]

This paper describes:

1. the perceived shortcomings of a systems design course curriculum in a traditional classroom setting;
2. the development of a non-traditional systems design course with the cooperation of a local industry partner;
3. examples of off-campus field trips to the industry partner that support systems design learning experiences;
4. the outcomes, feedback, and experiences from partnering with a local industry;[2]
5. additional student opportunities resulting from developing a partnership with a local industry.

Perceived Shortcomings to Traditional Systems Design Curriculum

Before I began a career in academia as a professor of (electrical) engineering, I worked in industry for nearly 20 years. A major part of my career was in the military performing duties as an avionics maintenance technician, a flight crewmember in remote operations in Alaska, an avionics systems engineer for the F-16 aircraft, and researcher for guidance and controls systems in an avionics laboratory. Once in front of the classroom, it did not take long before I noticed that my senior students had a good grasp of the individual subjects (circuits, digital electronics, microprocessors, mathematics, physics, etc.), but they lacked a solid understanding of how the pieces integrated and functioned in a sophisticated system. For example, in a design class, students asked me how an electric motor actually worked. When I described the fundamentals of how a motor worked, I also found myself describing to them how a motor is built piece by piece. How I wished I could take my students back to my roots; to a place where raw materials such as copper and iron are fabricated into individual parts and manufactured and integrated together to make an electric motor. I wanted to take them back with me in the field where I worked and learned hands-on. In my mind, having this real-world knowledge seemed both fundamental and essential to better understand how a motor works. Along with finding a way to provide students with the opportunity to study and understand sophisticated systems, I wanted to involve students in systems design and multidisciplinary teamwork. Again, these are concepts that are best learned about in the field. My solution to providing students with these practical experiences that they cannot get in the traditional classroom environment was by finding a local industry that would be interested in a partnership with the engineering department.

Choosing and Selling to the Local Industry Partner

Within a ten-mile radius of campus, I searched for an industry that had the best promise of providing systems engineering experience in a manufacturing environment. Several companies met this requirement. I chose to contact a company that was less than five miles from campus, GE Transportation Systems. The local GE facility manufactures diesel freight locomotives. The beauty of this (rail locomotive) system is that it is essentially a large moving power plant that creates electricity to power electric motors, which in turn move the wheels of the locomotive, which in turn pulls or pushes up to a hundred or so rail cars. These freight locomotives are comprised of a variety of systems: diesel engine system, propulsion systems, AC & DC motor systems, cooling systems, traction-control systems, power conversion systems, truck (wheel design) systems, remote monitoring and diagnostics systems, train control systems, rail signaling systems, and wireless communications systems. All these systems are integrated, mounted, and fastened on a system called the "platform." After a few phone calls, a meeting was set to discuss an academia-industry partnership with engineers and managers from GE. At the meeting I explained to GE that I was looking for a long-term relationship. I wanted to create an opportunity for my students to study systems and the integration and testing of such systems off-campus at their facility. I explained that I wanted my students to have a deeper knowledge and understanding of systems design and integration. In return, what I had to offer was the possibility that some of the students might become interested in their company as a student intern co-op or even become a full-time employee with knowledge in the areas of manufacturing and systems design and integration. There would also be guaranteed opportunities for GE to sponsor students with senior design projects that dealt with systems design. I agreed to be the students' faculty advisor on all GE-related projects. I also promised to be flexible and adaptive to my industry sponsor's ever-changing technical business needs.

Meeting Outcomes

This first meeting led to a series of discussions during which both parties agreed that the students and industry would benefit if there were a way to:

1. better connect theory taught in the classroom to real-world events;
2. enable students to be more knowledgeable in systems engineering and reliability engineering before graduation;
3. introduce the students to the benefit and use of written standards used in practice;
4. provide new employee plant safety training to all students;
5. discuss the need in design of the IEEE Code of Ethics and the National Code of Ethics for Engineers;
6. provide direct hire co-op and internships to students.

GE wanted the partnership to expose students to:

1. failures and failure rates;
2. cutting-edge technology;

3. how mechanical systems integrate with electrical systems;
4. the importance of quality and reliability;
5. interactions with mechanical and electrical engineers;
6. working in a multidisciplinary team that includes people from other fields; including business, computer science, and manufacturing.

The result was the creation of a course that would augment the senior design curriculum with the study of the systems and business design requirements of a railroad locomotive.[3]

Course Objectives

The following objectives were developed over time and with iterative inputs from the industrial partnership, the program's industrial advisory board, the author's continuing education of ABET outcomes, and faculty meetings pertaining to ABET accreditation. Throughout the course, students are expected to accomplish the following goals while working on a capstone design project for the industry partner.

1. Communicate effectively in oral, visual, graphical, and written modes
   a) During the project, students submit weekly progress reports that detail progress to date, tasks accomplished, tasks not accomplished (if applicable) with reasons why tasks were not accomplished, and a list of tasks to be accomplished for the following week.
   b) At the end of the project, students detail overall requirements, design, implementation, and results. They must present these details in a written final report, an oral presentation, and a visual presentation on a poster or equivalent.
2. Work effectively individually and in teams
   a) Students, in a team environment, distribute the work associated with defining a project, developing specifications, scheduling, and budgeting.
3. Have a commitment to quality, timeliness, and continuous improvement
   a) Students work to meet weekly deadlines associated with progress reports.
   b) Students test their design and demonstrate that it will meet specification requirements.
4. Identify social, economic, safety, quality, reliability, and ethical issues in an engineering technology problem and demonstrate that their solution addresses these issues
   a) Students show that their design has been evaluated to ensure system reliability.
   b) Students show that their design has been evaluated to ensure equipment and human safety.
5. Lifelong learning
   a) Students understand the need for lifelong learning and the opportunities that may be available for additional career development after graduation.
6. Organize and effectively manage an industrially-based project
   a) Students, in a team environment, demonstrate that their system design meets specification requirements.
   b) Students demonstrate that their system was completed within budgetary constraints.
   c) Students submit a final written report and oral presentation that detail overall requirements, design, implementation, and results for their capstone design project.

On-Campus and Off-Campus Learning Topics

The course that was developed is comprised of on-campus traditional classroom lectures and off-campus meetings. The on-campus classroom lectures discuss the following topics:

- Project definition
- Marketing requirements
- Reliability issues
- Maintainability
- Requirement specification development
- Design specifications
- Scheduling
- Budgeting
- Codes, standards, and safety issues
- Test matrices, integration, and testing
- Ethics and professionalism
- Lifelong learning
- Case study of an electronic guitar tuner[4]
- Teams and teamwork
- Program management
- Making a PowerPoint presentation
- Final report writing
- Mock presentation
- Guest lecturers from industry (scheduled where needed)

The off-campus sessions are held for two hours each week. During these sessions at the industry facility, the following topics are discussed:

1. Systems and Plant Safety

   All students receive plant and systems safety—the same training that a newly hired engineer would receive. Students also are issued safety glasses and ear protection. All students wear safety toe shoes at all times.

2. Systems Engineering

   Students learn about the interdisciplinary process that helps ensure that the customer's needs are satisfied throughout a system's entire life cycle. Also emphasized and explained during these sessions are:

   - Basic ideas in probability and statistics
   - Reliability engineering
   - Failure rates
   - Mission reliability
   - Mean time between failures
   - Mean downtime
   - Availability
   - Failure rates for electronic parts: MIL-HDBK-217E
   - Risk assessment
   - Failure mode and effects analysis (FMEA)
   - Total quality management
   - Statistical process control

Six-Sigma quality
ISO 9000

3. Communications and Navigations Systems

   In these sessions, the material focuses on wireless communications, as this is the method most commonly used on locomotives. Different wireless navigation and communication technologies are studied, such as:

   Satellite communications
   Cellular communications
   Digital radio
   Spread spectrum concepts, such as CDMA (code division multiple access)
   Global position satellite (GPS) systems

4. Engine Systems

   As the engine is the source of all power to the locomotive, the main topics of the engine systems sessions include:

   Combustion engine theory
   Gasoline engines versus diesel engines
   Four stroke diesel engines
   The 7FDL diesel engine, a specific industry partner locomotive engine design, and its components

   For diesel engine systems, students visit the manufacturing facility and observe how the different engine components are manufactured, assembled, and tested. In addition, students are able to see how diesel engines are reliant upon electrical engineering technology to be efficient. For example, electronic fuel injection optimizes the fuel efficiency of the engine and minimizes wasteful emissions.

5. Propulsions Systems

   AC and DC motors use the power generated by the diesel engine to propel the locomotive. So the propulsions systems sessions focus on the physical structure of the AC and DC motors and how they function to propel the locomotive.

   During the labs, students tour the factory where the AC and DC motors are manufactured from the ground up. One of the remarkable parts of this experience is that GE builds its motors from raw materials. The students have the rare opportunity to observe the life-size copper windings being shaped and wrapped with insulation before being inserted into the stator core. They also see how the motors are balanced for vibration and performance tested.

6. Remote Monitoring and Diagnostics[5]

   At this point in the course, students have seen the major components of a locomotive system. Now that the system is complete, the students learn about the importance of remote monitoring and diagnostics. These sessions discuss the types of sensors and equipment that are installed on board and how they are used to monitor key parameters such as oil pressure, oil temperature, fuel quantity, engine revolutions, and locomotive position. Since the transmission of the data from the locomotive to the home center is done through wireless communications, errors introduced in the communication process, such as bit errors, quantization errors, and sensor errors, and antenna type and placement are discussed.

Outcomes and Feedback

GE made the following observations about the quality and value of the students' work. "The students show great ownership of all project aspects, including scoping, defining, planning, and executing, and do a good job of applying their textbook and classroom knowledge to current, high-tech challenges. They deliver great results and we benefit from their work in several ways. We are able to resolve technical issues, keep our engineers current on college topics, and interest and evaluate potential new GE hires."

The student response to being off-site was mostly positive too. Students repeatedly express their excitement over being able to work and study in a real-world environment. According to one student, "It was great to see the immediate applications of theory to real-life problems and I learned good information about the reliability requirements for electronics." However, a small percentage (less than 10%) of the students had a hard time adapting to an active-learning environment. Some students simply prefer the traditional classroom setting. For example, some students commented that "driving off campus, takes a lot more time than walking across campus." Part of the problem too, was that one group of students met for ten weeks of off-campus learning each Friday between 3 p.m. and 5 p.m. Some of these students commented that this meeting time infringed on their social life. Yet, the students who embrace the active-learning environment have told me that it was a lot of work, but they now have a better understanding and appreciation for the field.

From my perspective as the faculty member that created the partnership and the instructor of the course, I found it to be very rewarding both from a professional teaching perspective, and from a nurturing perspective to my students.

Additional Benefits of an Industry Partnership

This partnership allowed 10-15% of my students to find work with the industry partner as a co-op or summer intern. Some of these same students were offered or accepted full-time positions. For each year of the partnership, two new and additional senior design projects were funded and sponsored. Several students were put on rotational assignments in the areas of field service, locomotive final assembly and testing, and maintenance and diagnostics service.[6] The field assignments took place in Colorado, Nebraska, or Montana. During this assignment, students worked with other field engineers, technicians, and customers. The feedback I received from both the students and industry partner was that this assignment provided an excellent opportunity for students to gain a greater understanding of customer needs. Also, as part of the off-site visits, the locomotive final assembly and testing assignment allowed students to see the integration of large complex system components and how the outputs of each component affect the functionality of the entire system. Students had the opportunity to use their knowledge of probability, statistics, and reliability at the maintenance and diagnostics service center, where information is received from locomotives in the field. In addition, for all student interns and co-ops, the industry partner provided and paid for formal six-sigma and leadership training.

One final benefit regarding equipment—GE also provided an additional lab for students. The company installed a six-ton locomotive wireless RF and navigation systems cab on the campus.

The cab soon became equipped with state of the art equipment, such as network analyzers, spectrum analyzers, signal generators, and PC computers. It has been supplied with underground power, a T1 Ethernet connection, and wireless Internet.

The industry partnership has provided new research opportunities with funding.[7] Funding amounts for projects soon exceeded $100,000. The industry partnership also provided funding and support to increase campus minority enrollment in science and engineering majors. For example, GE provided leadership seminars and committed funding to the campus' chapter of the National Society of Black Engineers. Last but not least, the industry partner provided female engineering personnel and funding to support the author with an on-campus outreach program for seventh and eighth grade female students.[8] This outreach program encourages grade school girls to become interested in engineering and the sciences by offering a day of hands-on seminars. The industry partner provided funding to purchase the equipment necessary for the author to lead students in a workshop that utilize portable GPS systems.

To date, approximately five engineering faculty, three graduate students, one full-time research associate and 50-75 undergraduate students have been part of the industry partnership described in this paper.

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