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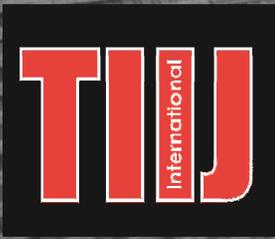
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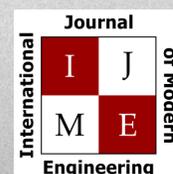
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TIIJ is published twice annually (fall/winter and spring/summer) and includes peer-reviewed articles that contribute to our understanding of the issues, problems, and research associated with technology and related fields. The journal encourages the submission of manuscripts from private, public, and academic sectors. The views expressed are those of the authors and do not necessarily reflect the opinions of TIIJ or its editors.

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4th IAJC/ISAM Joint International Conference

September 25-27, 2014 – Orlando, Florida



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The editors and staff at IAJC would like to thank you, our readers, for your continued support, and we look forward to seeing you at the upcoming IAJC conference. For this fourth IAJC conference, we will be partnering with the International Society of Agile Manufacturing (ISAM). This event will be held at the new Embassy Suites hotel in Orlando, FL, September 25-27, 2014, and is sponsored by IAJC, IEEE, ASEE, and the LEAN Institute.



EDITOR'S NOTE

Philip Weinsier, TIJ Editor-in-Chief

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The IAJC/ISAM Executive Board is pleased to invite faculty, students, researchers, engineers, and practitioners to present their latest accomplishments and innovations in all areas of engineering, engineering technology, math, science, and related technologies.

Selected papers from the conference will be published in the three IAJC-owned journals or 11 affiliate journals. Oftentimes, these papers, along with manuscripts submitted at-large, are reviewed and published in less than half the time of other journals. Publishing guidelines are available at www.iajc.org, where you can read any of our previously published journal issues, as well as obtain information on chapters, membership, and benefits.

I am pleased to report that, based on the latest impact factor (IF) calculations (Google Scholar method), the Technology Interface International Journal (TIJ), had a strong showing with an IF = 1.02 (in publication since 1996). TIJ's sister journals, the International Journal of Modern Engineering (IJME) and the International Journal of Engineering Research and Innovation (IJERI), also now have remarkable IF values equal to 3.00 and 1.58, respectively. Any IF above 1 is considered high, based on the requirements of many top universities, and places the journals among an elite group.

Currently, there is no official ranking system for journals that publish areas of engineering the way that TIJ, IJERI, and IJME do, but the following still apply:

- All three journals now are indexed in most well-known indexing databases including DOAJ, which is the most prestigious and comprehensive database for open-access journals worldwide.
- The journals now are indexed by hundreds of libraries worldwide, and in several states where there is near complete indexing across their university and college libraries.
- The journals now are indexed in the libraries of all 10 campuses of the University of California system and the 23 campuses of the California State University system.

The biggest achievement, though, is that now the journals also are indexed by all of the top 10 universities in the world:

- #1 California Institute of Technology
- #2 Harvard
- #3 Stanford
- #4 University of Oxford
- #5 Princeton University
- #6 University of Cambridge
- #7 Massachusetts Institute of Technology
- #8 Imperial College London
- #9 University of Chicago
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If you are interested in becoming a member of the IAJC International Review Board, send me (Philip Weinsier, IAJC/IRB Chair, philipw@bgsu.edu) an email to that effect. Review Board members review manuscripts in their areas of expertise for all three of our IAJC journals—IJME (the International Journal of Modern Engineering), IJERI (the International Journal of Engineering Research and Innovation), and TIJ (the Technology Interface International Journal), as well as papers submitted to the IAJC conferences. Please watch for updates on our website (www.IAJC.org), and contact us anytime with comments, concerns, or suggestions.

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IMPLEMENTATION OF A NEW MECHATRONICS ENGINEERING TECHNOLOGY DEGREE LEVERAGING INDUSTRY SUPPORT

Masoud Fathizadeh, Purdue University Calumet; Mohammad Zahraee, Purdue University Calumet; Greg Neff, Purdue University Calumet; Akram Hossain, Purdue University Calumet; James Higley, Purdue University Calumet; Niaz Latif, Purdue University Calumet

Abstract

Four years ago, Purdue University Calumet established a baccalaureate-level Mechatronics Engineering Technology degree program and created advanced-level courses in mechatronics with a focus on Packaging Automation. Three state-of-the-art laboratories with equipment donated by major packaging and automation equipment manufacturers were established. The new program was supported by the Packaging Machinery Manufacturers Institute (PMMI) and the National Science Foundation (NSF) with a Course, Curriculum, and Laboratory Improvement (CCLI) grant to develop course and laboratory materials as well as assessment and evaluation mechanisms. In this paper, the authors outline the student recruiting efforts, program, course, and laboratory development progress, along with assessment and evaluation methods.

Introduction

Most items purchased today use some sort of packaging. The market for packaged goods is steadily growing. Packaged goods constitute a trillion dollar business with the packaging portion worth several hundred billion dollars. Packaging, once labor intensive, now requires fast, accurate, and automated machinery. Packaging machines utilize electrical, mechanical, computer, and telecommunication equipment in their design. An engineer, who designs and maintains packaging machinery, must be knowledgeable in both the mechanical and electrical fields. In the past, packaging machinery manufacturers trained their own engineers in house, which took several years and a lot of costly trial and error. The few people receiving electrical and mechanical cross training in U.S. colleges and universities seldom find their way to packaging machine builders. Early in the development of the program (2009), its intent and foundations were published at an ASEE conference [1]. While there are many mechatronics engineering degrees at the baccalaureate level throughout the world [2-5], the ASME magazine [6] claims that only three U.S. universities offer mechatronics engineering degrees; and none of these programs suit the needs of the packaging industry [7-10]. Pack-

aging machine builders require the integration of constantly changing and improving commercial hardware, software, and networking protocols into automation systems. Universities have great difficulties integrating such expensive equipment into their curricula.

During the economic decline, packaging machine builders prospered, countercyclical to other areas of manufacturing. Packaging automation customers wanted increases in speed and efficiency with technical complexity requiring a higher level of expertise among machine designers. In the past decade, most packaging machines changed operation from mechanical to servo-driven systems [11-13].

This type of equipment requires expertise both in mechanical design and control. It is this chain of events that has driven the faculty at Purdue University Calumet (PUC) to establish the Mechatronics Engineering Technology program. The close collaboration between the faculty at PUC and the advisory board made up from automation and packaging machinery suppliers provides suggestions and recommendations for continuous improvement of the program. The Mechatronics Engineering Technology Program at PUC has the following goals:

- The program will provide a student-centered learning environment where students with Mechatronic interests and aptitude learn the applied mathematical skills, scientific principles, and mechatronics engineering technology topics in preparation for a wide variety of careers in related fields.
- The program will provide training at the individual topic, individual course, and certificate levels for individuals interested in learning mechatronics engineering technology topics, regardless of whether or not the student is pursuing a traditional degree.
- The program will provide technical assistance in mechatronics engineering technology-related areas to local businesses. The vision for the program is to be the preferred choice of students interested in learning mechatronics engineering technology topics at the bachelor's and graduate levels with a national viewpoint but concentrating on the development of the Midwest region.

- In order to accommodate the non-traditional nature of many of the PUC (Chicago metro-area) students, the Mechatronics Engineering Technology program offers courses during days and evenings. A few courses employ a distance-learning format if appropriate.

The Mechatronics Engineering Technology Bachelor of Science program produces graduates that:

1. are prepared for successful careers in the areas associated with the analysis, calculation, applied design, development, implementation, and oversight of advanced mechatronics (electromechanical) systems;
2. can advance in their careers and continue their professional development; and,
3. understand the overall human context in which engineering technology activities take place.

Industry Support Drives Program Progress

Industry sponsors and supports the Mechatronic Engineering Technology program in several ways. First, it was industry that requested the program to begin with, and the university tried to meet their needs. Second, industry provided modern equipment to equip several laboratories for student use, training, and research. Third, industry provides internship opportunities for both students and faculty. Fourth, industry sponsors research projects. And, finally, industry hires program graduates at both the undergraduate and graduate levels.

Based on the initial successes with the programs and largely due to industry support, two grant proposals were submitted to the National Science Foundation for funding and support [14]. The resulting funding dramatically improved six existing courses and created two new courses specifically for the program. Both program enhancements will improve student learning by providing activities that introduce new topics, build on existing topics, and then provide open-ended projects for students to bring together various areas of knowledge. Specifically, the two new courses provide integrating experiences with open-ended projects based on the needs of packaging machinery builders.

In addition, improvements to six existing courses were made. These courses will use the Mechatronics Engineering Technology Laboratories. Table 1 shows a summary of improvements in the existing courses.

Table 1. Improvement in the Existing Courses

| Course Name | Nature | Modified to Include |
|---|----------|--|
| Fluid Power | Existing | From primarily hydraulics to 40% hydraulics, 40% pneumatics, 20% vacuum |
| Machine Elements | Existing | Conveyors and control topics and created laboratory experiment and project for these topics |
| Electrical Power & Machinery | Existing | Motion control with servo motors and variable frequency drivers |
| Programmable Logic Controllers | Existing | Added human-machine interface (HMI) and relevant laboratory experiments |
| Power Electronics | Existing | Added power conditioning, advanced motion control and relevant laboratory experiments |
| Application of Computers in Process Control | Existing | System level integration of control elements. Virtual instrumentation and graphical programming. System design, control element specification, integration and high-level controller programming |

New Courses

Industrial Programming & Networking—This course is to include programming data management tools and networking sensors, controllers, and supervisory computers. After successfully completing the course, a student should be able to demonstrate knowledge in the following areas:

1. Networking smart-sensor transducers, controllers and final control elements
2. Monitoring, controlling, and programming mechatronics systems using virtual instrumentation and graphical software tools
3. Various industrial interface busses and protocols
4. Recognition of hardware specification and knowledge of integration
5. Configurable wireless sensors networks
6. Communication between platforms

Machine Design—This course is to include systems integration and project design. After successfully completing the course, a student should be able to demonstrate knowledge in the following areas:

1. Safety while working around machinery.
2. The ability to perform risk assessment of machinery.
3. The successful design and construction of the mechanical elements of the packaging machinery.

4. The successful specification, installation, programming, and troubleshooting of electrical controls of packaging machinery.

Laboratory Development

Three different laboratories were built to serve the following purposes: i) training basics, ii) implementation of automation equipment, and iii) training engineers, technicians, and end-users. The close collaboration between industry partners and PUC provided state-of-the-art equipment. PUC provided funding for upgrading and preparing the laboratory facilities. Two grants from the National Science Foundation facilitated the development of the curricula and experiments. The basic training equipment for the laboratory, provided by industry, is worth more than \$750,000 and is shown in Figure 1. The purpose of the laboratory is to teach the basic configuration of packaging systems. This lab contains:

1. Complete real-world pharmaceutical testing machine/conveyors—Shuttleworth Corporation.
2. Rockwell PLC setup coupled with servomotors—Rockwell Automation.
3. PLC setup ELAU—Schneider Electric
4. EATON variable frequency setup—EATON
5. Fastec in-line high-speed camera vision system—Fastec Imaging Corp.
6. Cognex high-speed camera—Cognex Corp.
7. HMI PanelView™ 600—Rockwell Automation
8. HMI unit with Video Design—Schneider Electric
9. Yaskawa MOTOMAN robot unit—Yaskawa Corp.
10. A wide range of electrical sensors—Balluff Inc.
11. NI-SCXI hardware setup coupled with LabVIEW™ software tools.



Figure 1. Mechatronics Basic Laboratory

The purpose of the second lab is to teach the integration of software and hardware into a working machine. This lab contains a complete real-world packaging machine donated by Morrison Container Handling. Figure 2 depicts this laboratory. These two laboratories are networked together to allow students to remotely control machines and collect data. The third laboratory is mostly used to train engineers, technicians, and end-users and is completely equipped and continuously updated by the industry partner. This laboratory has PLCs, VFDs, servo systems, and HMIs. Figure 3 shows one of the six equipment racks used in the laboratory. These laboratories are also used by students from the EET and MET programs as well as contract training.



Figure 2. Implementation Laboratory



Figure 3. One of the Six Equipment Racks Used to Train Engineers and Technicians

Student Recruiting Efforts

The School of Technology has put a lot of effort into recruiting new students for the Mechatronics Engineering Technology Program:

1. A new website was developed [15] to specifically address the program.
2. Students from different high schools and two-year colleges were invited to attend a half-day visit and laboratory demonstrations.
3. Over the last five years, faculty from the mechatronics program visited many packaging machinery manufacturers in Indiana, Illinois, and Wisconsin and provided information regarding the new program that resulted in mechatronics scholarships from several packaging machine builders and the Packaging Machinery Manufacturers Institute (PMMI). PMMI has been very supportive of the Mechatronics Engineering Technology program providing several scholarships since 2008. In many cases, these scholarships allow a student to attend classes when they would not otherwise be able to afford tuition. In addition, Morrison Container Handling Solutions, Glenwood Illinois, donated the Pat Sharkey Memorial Scholarship beginning in 2010.
4. Funds were secured to buy and partially outfit a trailer/mobile laboratory that can transport mechatronics equipment to area schools to pique interest.
5. Initial support for a summer STEM technology day camp with emphasis on mechatronics was offered by the Purdue Calumet School of Technology.
6. Articulation Contracts were signed with several universities and colleges worldwide for smooth transfer of student to PUC.

The Mechatronics Engineering Technology program at PUC started in the fall 2008 semester. Now, five years later, there are 31 students enrolled in the program. The first student completed his Bachelor of Science degree in May, 2011. Employer-paid internships are a key component of the program with two internships required to graduate. The internships ensure that the program graduates enter the workforce with some experience, making them ready to work right away without much additional training. The annual need is about a dozen internships for the current number of students. All graduates from the program were sought after by several local companies and were hired even before completing their coursework. In addition, student contests provide another avenue to recruit, motivate, and support students. Each year, four students under the supervision of a professor in the Mecha-

tronics Engineering Technology program participate in the Student Design Contest held at PACK Expo, which is held in Las Vegas or Chicago in early October.

PMMI University, the educational arm of PACK Expo, organizes a competition to give packaging students practical experience and expose them to all that PACK Expo has to offer. Students from many universities participate in the competition each year. The competition requires the students to find a unique solution to a real-world packaging issue; for example, creating an automated palletizing system that would be fastest and least expensive to produce and maintain. The competition usually begins on the Packaging Equipment Expo floor as the students, face to face with vendors, try to develop a solution to the given problem. They work late into the night and wake up very early the next day to produce a paper and a 20-minute presentation on their solution. The team put on a solid performance in front of industry leaders. During last three competitions, PUC students ranked third, second, and first and they were rewarded for their efforts. Their solution took into account environmental impact, energy consumption, ease of use, and cost considerations. The student-contest PMMI sponsors were a great help. The contests help bring the students to Pack Expo, and the PackExpo experience really raises their enthusiasm level.

Program Accreditation

The Mechatronics Engineering Technology program was initially designed with accreditation in mind. Based on general criteria from the Accreditation Board for Engineering and Technology (ABET), the program started with a strategic plan, program educational objectives, an assessment and continuous improvement plan. ABET lists the a-k outcomes [16], [17] in their accreditation criteria. The program educational objectives are based on these outcomes. The following program objectives that are shown in Tables 2 through 4 were prepared for successful careers in the areas associated with the analysis, applied design, development, implementation, and oversight of advanced Mechatronic systems. No program criteria for programs with the modifier “mechatronics” are available as this will be the first U.S. program of its type to seek accreditation.

Continuous Improvement

In the past few years, Purdue University Calumet has adopted the continuous improvement approach to all areas of accreditation, evaluation, and improvement. The university, school, department, and program plans are aligned to focus on goals and outcomes. As part of this pro-

Table 2. Program Educational Objective 1

| Objective 1 Metrics | | Assessment Methods |
|---|--|---|
| 1.1 Graduate first year job placement results will be high. | | Placement Statistics |
| 1.2 Graduates will agree that their education prepared them for an entry-level job. | | Alumni Survey |
| 1.3 Employers will agree that mechatronics program graduates are prepared for an entry-level job. | | Employer Survey |
| Objective 1 Program Outcomes | ABET Criterion: Students and Graduates (a-k) | Assessment Methods |
| 1.1 Students will demonstrate proficiency in mechanical design, materials, manufacturing processes, and controls. | a, b, c, d, f | 1. Course Embedded 2. CMfgT exam results 3. Senior Projects |
| 1.2 Students will demonstrate proficiency in applied mathematics and science. | b, c, f | 1. Course Embedded 2. CMfgT exam results |
| 1.3 Students will demonstrate proficiency in computer applications. | a, d, g | 1. Course Embedded 2. Senior Projects |
| 1.4 Students will demonstrate proficiency in solving open-ended problems requiring multiple areas of knowledge. | a, b, c, d, f | 1. Course Embedded 2. Senior Projects 3. Exit Survey |

Table 3. Program Educational Objective 2

| Objective 2 Metrics | | Assessment Methods |
|--|--|--|
| 2.1 Some portion of our graduates will earn a promotion within a reasonable time of starting their careers. | | Alumni Survey |
| 2.2 Some portion of our graduates will go on to graduate school. | | Alumni Survey |
| 2.3 Some portion of our graduates will attend seminars, short courses, and additional courses and earn related certifications. | | 1. Alumni survey 2. Employer Surveys |
| Objective 2 Program Outcomes | ABET Criterion: Students and Graduates (a-k) | Assessment Methods |
| 2.1 Students will demonstrate a level of effectiveness expected by employers when they produce written documents, deliver oral presentations, and develop, prepare and interpret visual information. | a, g, i | 1. Course Embedded 2. Senior Projects |
| 2.2 Students will be exposed to the value of professional societies in their careers. | h | 1. Enrollment Summary Data 2. Exit Survey |
| 2.3 Students will demonstrate proficiency in managing projects. | e, f, g, I, j | 1. Course Embedded 2. Senior Projects 3. Exit Survey |
| 2.4 Students will understand the advantages of self-learning. | h, k | 1. Course Embedded 2. Exit Survey |

cess, the mechatronics program meets as a program, with its advisory committee, and as a department at scheduled intervals to assess and evaluate the program. Following a Six Sigma approach, the mechatronics program evaluates the data, and even data meeting expectations are examined and reviewed for causes of variance. Proper actions are then taken by the group. These meetings follow specified agendas to ensure that pertinent areas are evaluated. A rigorous evaluation of the assessment results has been put in place to drive continuous improvement of the program.

Individual faculty members are responsible for the course embedded assessments and student evaluation updates. The mechatronics group discusses survey results and decides upon needed changes as a whole. Alumni and employer surveys play an important role in assessing and evaluating program objectives. Surveys were developed based on the program’s strategic plan.

The following Threshold Levels for Outcomes have been established:

- a. If the Course Embedded Assessment (from tests, labs, projects, etc.) is less than 60%, it needs attention.
- b. If the Student Evaluation of a course objective falls below 3.0, it requires attention.
- c. If an Exit, Alumni, or Employer Survey value is less than 3.5, more attention is needed.

The data shown in Tables 5 and 6 are the survey results from one Mechatronics Engineering Technology alumni and employer survey that were available at the time this report was written. Note that Purdue University Calumet graduated one student from the Mechatronics Engineering Technology program in the spring of 2011. An additional student graduated in fall 2012. The results of Course Outcome and Course Objective Assessments are shown in Tables 7 and 8, respectively.

Table 4. Program Educational Objective 3

| Objective 3 Metrics | Assessment Methods | |
|--|--|--|
| 3.1 Graduates will function effectively in diverse work teams. | Alumni and Employer Surveys | |
| 3.2 Graduates will effectively apply ethics to job-related decisions. | Alumni and Employer Surveys | |
| 3.3 Graduates will communicate effectively on their jobs. | Alumni and Employer Surveys | |
| Objective 3 Program Outcomes | ABET Criterion: Students and Graduates (a-k) | Assessment Methods |
| 3.1 Students will have exposure to situations that develop a sense of personal responsibility and accountability for one's individual actions and performance. | i, k | 1. Course Embedded 2. Exit Survey |
| 3.2 Students will have exposure to situations that develop their philosophy and appreciation for human differences. | i, j | 1. Course Embedded 2. Exit Survey |
| 3.3 Students will be able to demonstrate the ability to communicate in individual and team settings. | e, g | 1. Course Embedded 2. Senior Projects |
| 3.4 Students will demonstrate proficiency in assisting others in a group. | e, g | 1. Course Embedded 2. Senior Projects 3. Exit Survey |

Table 5. Mechatronics Engineering Technology Alumni Survey

| | Assessed Skill | # Resp. | Avg. Score | Target Score |
|---|---|---------|------------|--------------|
| 1 | Solving Technological Problems | 1 | 5 | 3.5 |
| 2 | Designing applied systems | 1 | 5 | 3.5 |
| 3 | To assume technical leadership | 1 | 5 | 3.5 |
| 4 | To assume managerial leadership | 1 | 5 | 3.5 |
| 5 | Computer application skills | 1 | 5 | 3.5 |
| 6 | Life-long learning | 1 | 5 | 3.5 |
| 7 | Effectiveness in working with diverse groups/teams at job | 1 | 5 | 3.5 |
| 8 | Oral and written communication skills at job | 1 | 4 | 3.5 |

Table 6. Mechatronics Engineering Technology Employers' Survey

| | Assessed Skill | # Resp. | Avg. Score | Target Score |
|---|--|---------|------------|--------------|
| 1 | Preparedness to function on an entry-level job | 1 | 5 | 3.5 |
| 2 | Preparedness to learn and apply state-of-the-art technology | 1 | 3 | 3.5 |
| 3 | Effectiveness in working with diverse groups/teams at job | 1 | 4 | 3.5 |
| 4 | Ability to assume technical leadership | 1 | 3 | 3.5 |
| 5 | Understanding and application of ethics in job-related decisions | 0 | NA | 3.5 |
| 6 | Oral and written communication skills at job | 1 | NA | 3.5 |

Table 7A. Course Outcome Program Assessment 2011

| Industrial Programming and Networking | | | | | | | | | | | | | | | |
|---|--|----------------|------------|----------------|------------|----------------|-------------|----------------|-----------|----------------|--|-------|-------|-------|-----------------------------|
| Assessment of Course Objectives and Student Feedback | | | | | | | | | | | | | | | |
| Semester: Fall 2011 | | | | | | | | | | | | | | | |
| Course Objectives | Course Objectives Assessment Tools (Target Score =70%) | | | | | | | | | | Student Feedback on Course Objectives (Target Score: 3.00 out of 4.00) | | | | |
| | Mid Term Exams | Avg. Score (%) | Final Exam | Avg. Score (%) | Labs | Avg. Score (%) | Projects | Avg. Score (%) | Home work | Avg. Score (%) | E (4) | G (3) | A (1) | P (1) | Composite Score out of 4.00 |
| 1. Network smart sensors, transducers, controllers, final control elements and Human Machine Interface (HMI) | Project I | 75 | Final Exam | 78 | LAB 1,2 | 85 | | | | | 6 | 0 | 0 | 0 | 4.00 |
| 2. Various industrial interface buses, protocols and communication among platforms | Project II | | Final Exam | 80 | Project II | 87 | | | | | 5 | 1 | 0 | 0 | 3.83 |
| 3. Recognition of hardware specification and knowledge of integration. | Project II | 74 | Final Exam | 79 | Project I | 84 | Project I | 86 | | | 4 | 2 | 0 | 0 | 3.67 |
| 4. Set up network of multiple controller, Human Machine Interface (HMI), other field devices. | Project III | 76 | Final Exam | 80 | LAB 2 | 85 | | | | | 6 | 0 | 0 | 0 | 4.00 |
| 5. Perform standardization in industrial programming. | LAB 1 | 78 | Final Exam | 82 | LAB 2 | 82 | Project III | 86 | | | 5 | 0 | 1 | 0 | 3.67 |
| 6. Design and configure graphical screens for HMI (Human Machine Interface) Units. | LAB 2 | | Final Exam | | LAB 2 | 79 | | | | | 5 | 1 | 0 | 0 | 3.83 |
| Instructor's Comments: The instructor will address and take a corrective action on any objective whose outcome score is less than 70%. The composite score for the student feedback exceeds the target score of 3:00. This is an indication that the course objectives were met from the student point of view. | | | | | | | | | | | Number of Responses:6 | | | | |

Summary

The new Mechatronics Engineering Technology Program at Purdue Calumet has provided the following:

1. Implementation of the new curriculum by enhancing six existing courses in electrical and mechanical engineering technology; development of two new mechatronics engineering technology courses; and establishment of three new mechatronics laboratory facilities to provide hands-on experience in designing, controlling, and integrating packaging machinery systems.
2. Incorporation of experiential learning into the curriculum so that the courses are beneficial, practical, and appealing to employers, industry, and students. The project goals will be accomplished through a triadic partnership between PUC, the packaging industry,

and the awarded NSF \$150,000 CCLI and \$650,000 ATE grants. Formative and summative evaluations were performed at appropriate times for assessment of curricular materials, objectives, outcomes, student learning, experiential learning, and overall impact of the program.

3. New employment opportunities for graduates and the satisfaction of cooperation with mechatronics engineering technology programs and industry professionals.
4. Continuous collaboration between industry and university to improve the curricula and laboratories.

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Table 7B. Course Outcome Program Assessment 2012

| Industrial Programming and Networking | | | | | | | | | | | | | | | |
|---|--|----------------|------------------|----------------|-----------|----------------|-------------|----------------|----------|----------------|--|-------|-------|-------|-----------------------------|
| Assessment of Course Objectives and Student Feedback | | | | | | | | | | | | | | | |
| Semester: Fall 2012 | | | | | | | | | | | | | | | |
| Course Objectives | Course Objectives Assessment Tools (Target Score =70%) | | | | | | | | | | Student Feedback on Course Objectives (Target Score: 3.00 out of 4.00) | | | | |
| | Mid Term Exams | Avg. Score (%) | Final Exam | Avg. Score (%) | Labs | Avg. Score (%) | Projects | Avg. Score (%) | ome work | Avg. Score (%) | E (4) | G (3) | A (1) | P (1) | Composite Score out of 4.00 |
| 1.Network smart sensors, transducers, controllers, final control elements and Human Machine Interface (HMIs) | Problem 1,2,3,4 | 78 | Prob. 1,2 | 78 | LAB 1,2 | 83 | | | | | 7 | 1 | 1 | 0 | 3.67 |
| 2. Various industrial interface buses, protocols and communication among platforms | Problem 5,6 | 80 | Prob. 3,4,5, 6,7 | 79 | LAB 3 | 85 | | | | | 6 | 2 | 1 | 0 | 3.56 |
| 3. Recognition of hardware specification and knowledge of integration. | Problem 9 | 82 | Prob. 12 | 80 | LAB 4 | 86 | Project I | 85 | | | 8 | 1 | 0 | 0 | 3.89 |
| 4. Set up network of multiple controller, Human Machine Interface (HMI), other field devices. | Problem 8 | 76 | Prob. 8,9,10 | 83 | LAB 4,5 | 80 | | | | | 8 | 0 | 1 | 0 | 3.78 |
| 5. Perform standardization in industrial programming. | Problem 6,7 | 78 | Prob. 11 | 85 | LAB 6,7,8 | 86 | Project III | 88 | | | 8 | 1 | 0 | 0 | 3.89 |
| 6. Design and configure graphical screens for HMI (Human Machine Interface) Units. | Problem 8 | 85 | Prob. 11 | 84 | LAB 9,10 | 81 | | | | | 7 | 1 | 1 | 0 | 3.67 |
| Instructor's Comments: The instructor will address and take a corrective action on any objective whose outcome score is less than 70%. The composite score for the student feedback exceeds the target score of 3:00. This is an indication that the course objectives were met from the student point of view. | | | | | | | | | | | Number of Responses:9 | | | | |

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Table 8A. Course Objectives and Student Feedback Assessment for 2011

| Industrial Programming and Networking | | | | | |
|---|--|----------|----------------|----------|-----------|
| Assessment of Students Outcomes | | | | | |
| Proposed ABET Criterion Satisfied: a, b, c, d, f and g | | | | | |
| Student Outcomes (Matched to ABET a, b, c, d, f, and g) | Semester: Fall 2011 | | | | |
| | Student Feedback (Composite Target Score=3.00) | | | | |
| | Excellent (4) | Good (3) | Acceptable (2) | Poor (1) | Composite |
| a. As a result of this course, my ability to select and apply the knowledge, techniques, skills, and modern tools of my discipline to broadly-defined engineering technology activities can be rated as, | 6 | 0 | 0 | 0 | 4.00 |
| b. As result of this course, my ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies can be rated as, | 5 | 1 | 0 | 0 | 3.83 |
| d. As a result of this course, my ability to conduct the standard tests and measurements, to conduct, analyze, and interpret experiments, and to apply experimental results to improve processes can be rated as, | 4 | 2 | 0 | 0 | 3.67 |
| e. As a result of this course, my ability to design systems, components, or processes for broadly-define engineering technology problems appropriate to program educational objective can be rated as, | 6 | 0 | 0 | 0 | 4.00 |
| f. As a result of this course, my ability to identify, analyze, and solve broadly-defined engineering technology problems can be rated as, | 5 | 0 | 1 | 0 | 3.67 |
| g. As a result of this course, my ability to apply written, oral, and graphical communication in both technical and non-technical environments, and ability to identify and use appropriate technical literature can be rated as, | 5 | 1 | 0 | 0 | 3.83 |
| Instructor Comments: The composite score exceeds the target score that is set at 3:00 on the scale of 4. Hence, the course met the specified criteria and no action is needed at this time. | Number of Responses: 6 | | | | |

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Table 8B. Course Objectives and Student Feedback Assessment for 2012

| Industrial Programming and Networking | | | | | |
|---|--|-------------|-------------------|-------------|-----------|
| Assessment of Students Outcomes | | | | | |
| Proposed ABET Criterion Satisfied: a, b, c, d, f and g | | | | | |
| Student Outcomes (Matched to ABET a, b, c, d, f, and g) | Semester: Fall 2012 | | | | |
| | Student Feedback (Composite Target Score=3.00) | | | | |
| | Excellent (4) | Good (3) | Acceptable (2) | Poor (1) | Composite |
| a. As a result of this course, my ability to select and apply the knowledge, techniques, skills, and modern tools of my discipline to broadly-defined engineering technology activities can be rated as, | 7 | 1 | 1 | 0 | 3.67 |
| b. As result of this course, my ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies can be rated as, | 6 | 2 | 1 | 0 | 3.56 |
| c. As a result of this course, my ability to conduct the standard tests and measurements, to conduct, analyze, and interpret experiments, and to apply experimental results to improve processes can be rated as, | 8 | 1 | 0 | 0 | 3.89 |
| d. As a result of this course, my ability to design systems, components, or processes for broadly-define engineering technology problems appropriate to program educational objective can be rated as, | 8 | 0 | 1 | 0 | 3.78 |
| f. As a result of this course, my ability to identify, analyze, and solve broadly-defined engineering technology problems can be rated as, | 8 | 1 | 0 | 0 | 3.89 |
| g. As a result of this course, my ability to apply written, oral, and graphical communication in both technical and non-technical environments, and ability to identify and use appropriate technical literature can be rated as, | 7 | 1 | 1 | 0 | 3.67 |
| Instructor Comments: The composite score exceeds the target score that is set at 3:00 on the scale of 4. Hence, the course met the specified criteria and no action is needed at this time. | Number of Responses: 9 | | | | |

Biographies

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GEARS: AN OPPORTUNITY TO INTRODUCE AND REINFORCE STEM THROUGH ROBOTICS

Basile Panoutsopoulos, Central Connecticut State University

Abstract

Integrated knowledge of various disciplines of STEM (science, technology, engineering, and mathematics) provides a complete picture of the modern interdisciplinary nature of science and technology. In this paper, the gear, a mechanical component, is presented along with its physical properties, technological implementations, engineering description, and mathematical modeling. All these fields are interrelated and, presented as such, they are not isolated. The technological implementation is presented in the Lego Robotics context.

The proposed integrated approach can be implemented in a Robotics class or outreach activity to enhance, apply, and relate with the real world the various disciplines that can be used to add meaning and context to the robotics activity. It is proposed to transform the currently empirical activity to a scientific and technological education. In this paper, the author examines an approach to introduce the gear, a mechanical component, and its properties (physics - mechanics) along with calculations (mathematics), using other available components (technology) as tools for solving engineering-related problems. The Lego artifacts have been proven useful tools for introducing the STEM disciplines in both theory and practice.

Introduction

The importance of STEM components for preparing tomorrow's professionals in the sciences and its applications has been reported previously [1-3]. The importance of applications in research has also been reported by Stanley et al. [4]. As part of this effort, and specifically to integrate the various components of STEM, the gear, a mechanical component, is presented, modeled, and applied. A gear is a rotating machine part having cut teeth. Gears are used to transmit mechanical energy from one point to another. To establish a connection path between two points, a number of gears are meshed in order to provide a linking path and transmit the power. Gear systems can change the magnitude and direction of the velocity and torque of a power source. Gears mesh with rotating gears, in which case the rotational motion is transmitted as rotational; or mesh with a rack (a straight-toothed part) in which case the rotational motion is

transformed to translational. Figure 1 illustrates a typical rotational gear meshed with a linear gear, a rack [5]. The main characteristic of a gear is the teeth. Rotational gears are rotating around their shaft and the teeth are distributed along the circumference around the gear. The thickness of each tooth, t , and the spaces between the teeth are constant.

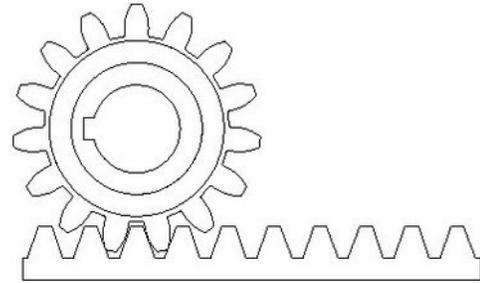


Figure 1. Typical Rotational and Rack Gears

The gears used in this study were components of the Lego Technic set. There is a variety of available gear designs, both rotational and linear. The available rotational sizes are shown in Table 1. The variety of available gears allows the implementation of a range of designs.

Table 1. Lego Gear Designs

| |
|--|
| 8-tooth, 16-tooth, 24-tooth, and 40-tooth spur gears |
| 12-tooth, 20-tooth, and 36-tooth double-bevel gears |
| 12-tooth and 20-tooth single-bevel gears |
| 16-tooth clutch gear |
| 24-tooth friction gear |

Gears are connected to motors that transform electric energy, stored in the batteries, to rotational mechanical energy. Safety is implemented via the 24-tooth friction gear that slips when a certain amount of torque is put on it to prevent motors from damaging any parts or burning themselves out. Figure 2 illustrates a number of LEGO gears [6]. The analog of the mechanical component to gears is the pulley. The teeth of a gear prevent slipping, which is an advantage over a pulley.

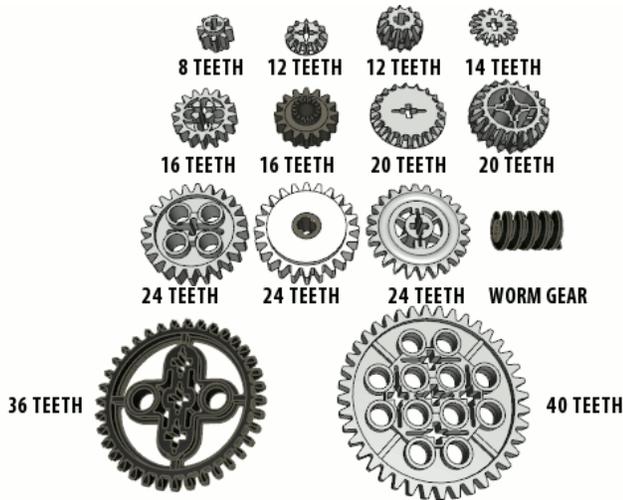


Figure 2. Illustration of the Various Types of Gears in Lego

Description of Gears and their Properties

An ideal mechanical system does not have losses; the input power, P_i , is equal to the output power, P_o . The model of an ideal, lossless mechanical system or mechanism provides a good approximation to the understanding of the physical operation of the various mechanisms and to the mathematical derivation of the various relationships among the characteristics of gears and a system of gears. The characteristics of an ideal mechanism, a conservative isolated system, are shown in Table 2.

Table 2. Characteristics of an Ideal Mechanism

| |
|--|
| Isolated: Transmission of power without adding to or subtracting from it. |
| Sourceless: Absence of a power source. |
| Lossless: No losses or frictionless. |
| Rigid: It is constructed from rigid parts that do not deflect or wear. |
| Constant gear ratio: Effect on the speed of the two gears. |
| Constant gear ratio: Effect on the torque of the two gears. |
| Speed-Torque: The faster the gear turns, the lower the torque. The slower the gear turns, the higher the torque. |

The understanding of the behavior of a real system starts with the study of approximate idealized models. The performance of real systems is obtained, to a good approximation, from the ideal by introducing proper values for friction, deformation, and wear. These factors are usually neglected in the study of a first-degree approximation [7]. The following material will show the characteristics, modeling, and

description of gears. The material can be introduced to and integrated in robotics projects.

A typical mechanical system, considered from the energy per unit time, or power point of view, is shown in Figure 3.

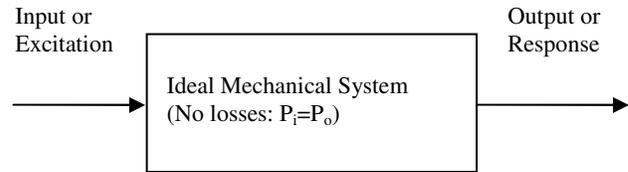


Figure 3. Illustration of the Single-Input Single-Output Ideal (Lossless) Mechanical System

The power relationship in a mechanical system states that the power is the product of force and velocity.

$$P = F \cdot v \quad (1)$$

For rotational systems this is equivalent to the product of the torque and angular velocity.

$$P = T \cdot \omega \quad (2)$$

The input power to a gear system with a torque T_i applied to the drive gear which rotates at an angular velocity of ω_i is

$$P_i = T_i \omega_i \quad (3)$$

Because the system is ideal, by hypothesis, the input power is equal to the output power. Then the output torque T_o and angular velocity ω_o of the output gear must satisfy the following relationship:

$$\begin{aligned} P_i &= P_o \\ T_i \omega_i &= T_o \omega_o \end{aligned} \quad (4)$$

That is, the product of torque times the angular velocity is constant. But its two factors can vary as long as the product is constant. This relationship is important and is expressed by the following definition.

Mechanical advantage is the factor of multiplication of force or torque in a gear system:

$$MA = \frac{T_o}{T_i} = \frac{\omega_i}{\omega_o} \quad (5)$$

The expression for MA shows that, for an ideal mechanism, the mechanical advantage is equal to the input-output angular speed ratio and to the output-input torque ratio. The mechanical advantage is a measure of the force or torque amplification or reduction of a mechanical system. The torque and angular velocity are inversely analogous (i.e., the higher the torque, the lower the angular speed). In a lossless or ideal system the input power is transmitted over the gears of the system until the desired amplification or reduction is seen at the output. Mechanisms are mechanical components designed to translate forces and movements in this way and are described by the mechanical advantage.

Pressure angle is the angle that the point—at which the teeth of two gears touch as they rotate—makes with the radius of the gear. Proper operation of the gears requires that both teeth must touch at the same angle. An uneven pressure angle between two gears will wear them out faster. Pitch circle is a theoretical circle that has its center at the center of the gear and its radius as half the height of the teeth (see Figure 4). The pitch circles of a pair of mating gears are tangent to each other. Pitch diameter (DP), or simply pitch, is the number of teeth (N_T) divided by the diameter (D) of the gear [8] and represents the number of teeth on a pitch circle of 1" diameter. Common pitches are 12 (big teeth), 24, 32, 48, and 64 (fine teeth).

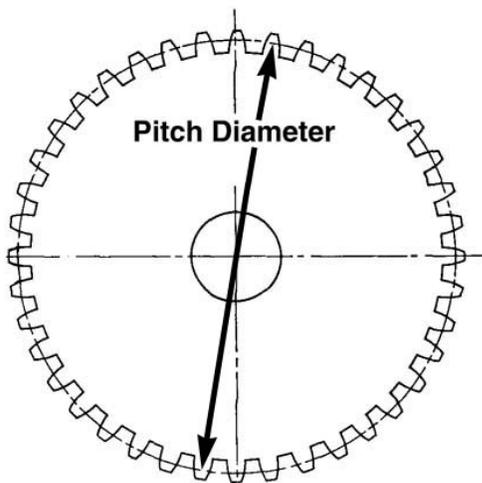


Figure 4. Definition of the Pitch Diameter in a Gear

$$DP = \frac{N_T}{D} \quad (6)$$

Circular pitch, p , is the distance, measured on the pitch circle, from a point on one tooth to a corresponding point on an adjacent tooth. The circular pitch is the equivalent of one tooth which, in turn, is equal to the sum of the tooth thickness and the width of the space.

The distance between the shafts of two gears' pitch diameter is a design parameter determined during the design of a structure involving gears [9]. It can be determined by adding the pitch radius of the two gears, as shown in Figure 5. Proper design requires that the teeth of the gears do not slide (to avoid friction and early wear) but rather roll against each other. The distance between the shafts of the two gears is the sum of the radii of the pitch circles of the gears. The diameter of a gear's pitch can be measured from the top of one gear tooth to the bottom of the opposite gear tooth. A system of rotational gears requires proper alignment of the gears at the appropriate distance between their shafts. Figure 5 illustrates the process. Positioning the gears at the correct distance from each other (neither too close such that they will produce too much friction, nor too far apart such that they affect the pressure angle) minimizes the stress, maximizes the life, and increases the efficiency of the gear mechanism.

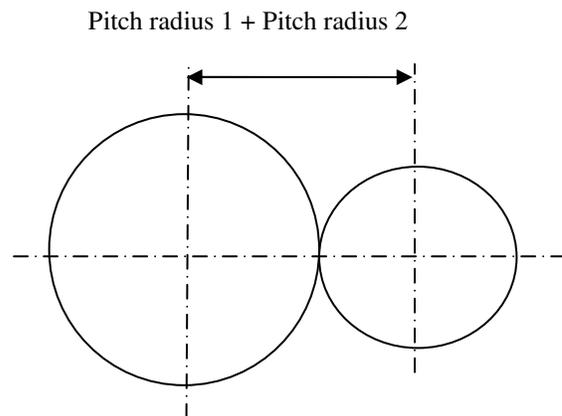


Figure 5. Illustration of the Process for Determining the Distance Between the Shafts of Two Gears

Gears: Types, Connections, and Properties

Gears in the Lego set can be classified as spur, bevel, and worm. In the following sections, each is introduced along with pertinent definitions [10], [11].

Spur gears consist of teeth parallel to their axis of rotation. They are used to transmit rotational motion from one shaft to another. The shafts are parallel to each other. Rotation of one gear in a system of gears rotates all the gears in the system. The gear that turns first is called the driving gear. The other gears are called followers. The spur gear system is the simplest one. Spur gears have three effects: Change angular or rotational speed, change torque, and change direction of rotation.

Proper construction of a gear system requires that the

system is constructed such that the gears spin easily; there is no friction between them and the supporting beam by inserting the appropriate bushing between the two. Figure 6 shows the profile [12], while Figure 7 shows the implementation of the driver and follower gears using Lego parts.

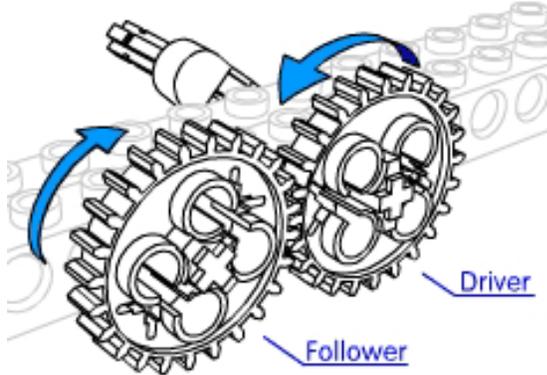


Figure 6. Driver and Follower Gears

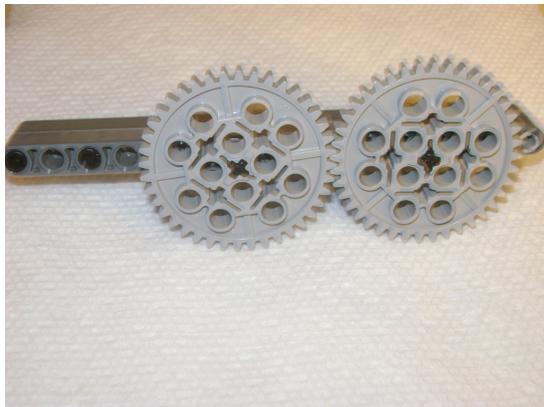


Figure 7. Implementation of Driver and Follower Gears using Lego

Modeling of a Gear Mechanism

A simple gear train with two gears was presented by Uicker et al. [13]. The input gear, G_i , drives the output gear G_o . Gear teeth are designed so that the pitch circles of the two gears roll on each other without slipping. The linear velocities, v , of the points of contact of the two pitch circles are the same:

$$v = \omega_i r_i = \omega_o r_o \quad (7)$$

The input gear G_i has radius r_i and angular speed ω_i , and meshes with output gear G_o of radius r_o and angular speed ω_o . The linear speed of two gears at the point of contact is

the same, at which point the speed ratio of the two gears rolling without slipping on their pitch circles is:

$$R = \frac{\omega_i}{\omega_o} \quad (8)$$

Substituting Equation (7) into Equation (8) yields

$$R = \frac{\omega_i}{\omega_o} = \frac{r_o}{r_i} \quad (9)$$

Furthermore, substituting Equation (6) into Equation (9) yields

$$R = \frac{\omega_i}{\omega_o} = \frac{r_o}{r_i} = \frac{N_o}{N_i} \quad (10)$$

In other words, the gear ratio, or speed ratio, is inversely proportional to the ratio of the radii of the pitch circles and the number of teeth of the two gears.

Rotational Speed Ratio

The pitch, p , of a gear is the distance between the equivalent points on two teeth, the tooth thickness, t , and the width of the space, s , and is represented by Equation (11):

$$p = t + s \quad (11)$$

Measurement with a micrometer can provide the pitch, which can be verified from the following calculations. The pitch of a gear, G_i , can be computed from the circumference of the gear divided by the number of teeth N_i :

$$p = \frac{2\pi r_i}{N_i} \quad (12)$$

Proper gear operation requires that for two gears G_i and G_o mesh smoothly and have the same size teeth, which in turn provides the same pitch p :

$$p_i = p_o \quad (13)$$

$$p_i = \frac{2\pi r_i}{N_i}, \quad p_o = \frac{2\pi r_o}{N_o} \quad (14)$$

Substituting Equation (14) into Equation (13) yields

$$\frac{2\pi r_i}{2\pi r_o} = \frac{N_i}{N_o} \quad (15)$$

Equation (15) shows that the ratio of the circumference, the diameters, and the radii of the two meshing gears is equal to the ratio of their number of teeth:

$$\frac{r_o}{r_i} = \frac{N_o}{N_i} \quad (16)$$

Substituting Equation (7) into Equation (16), yields

$$R = \frac{\omega_i}{\omega_o} = \frac{r_o}{r_i} = \frac{N_o}{N_i} \quad (17)$$

Alternatively, the gear ratio of a gear train is the ratio of the angular velocity of the input gear to the angular velocity of the output gear. The number of teeth on a gear is proportional to its circumference, which is proportional to the radius of its pitch circle; this means that the ratio of the radii equals the ratio of the number of teeth. The gear ratio indicates the change in speed and torque of the rotating axles. Equation (17) is identical to Equation (10) but derived in an alternative way.

For the special case of a gear train with two gears, the gear ratio R is

$$R = \frac{\omega_i}{\omega_o} = \frac{N_o}{N_i} \quad (19)$$

This equation shows that if the number of teeth on the output gear, G_o , is larger than the number of teeth on the input gear, G_i , then the input gear must rotate faster than the output gear. As an example, consider 8-tooth and a 40-tooth spur gears. The gear ratio is:

$$R = \frac{40}{8} = 5$$

The speed ratio for a pair of meshing gears can be computed from ratio of the radii of the pitch circles and the ratio of the number of teeth on each gear, its gear ratio. The 8-tooth gear rotates five turns of for every one turn of the 40-tooth gear. Alternatively, the 40-tooth gear rotates five times slower than the 8-tooth gear; that is, the angular speed of the 40-tooth gear is five times less than the 8-tooth gear. Similarly, this means that the 40-tooth gear has five times the torque than the 8-tooth gear.

Gear teeth are designed such that the number of teeth on a gear is proportional to the radius of its pitch circle. The pitch circles of meshing gears roll on each other without slipping. Gearing up is the condition when the follower turns faster than the driving gear. The driving gear has more

teeth than the follower and the linear velocity increases while the torque is reduced. Gearing down is the condition when the follower turns slower than the driving gear. The driving gear has fewer teeth than the follower and the linear velocity decreased while the torque is increased. The gearing up and gearing down profiles of gears are shown in Figures 8 and 10, respectively [14], while Figures 9 and 11 show the respective implementations using Lego pieces.

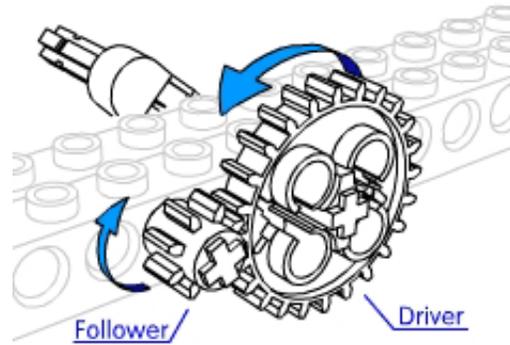


Figure 8. Gearing Up using Driver and Follower Gears

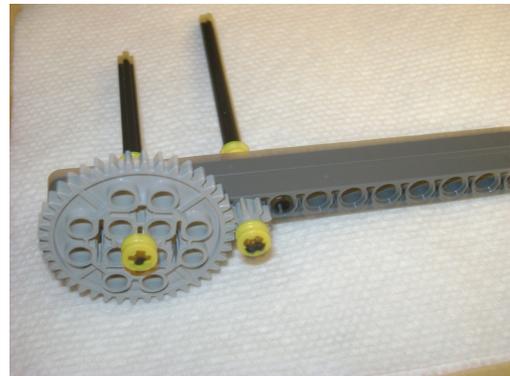


Figure 9. Implementation of Gearing Up Driver and Follower Gears using Lego

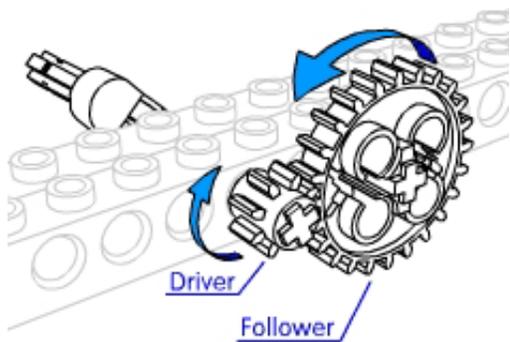


Figure 10. Gearing Down using Driver and Follower Gears

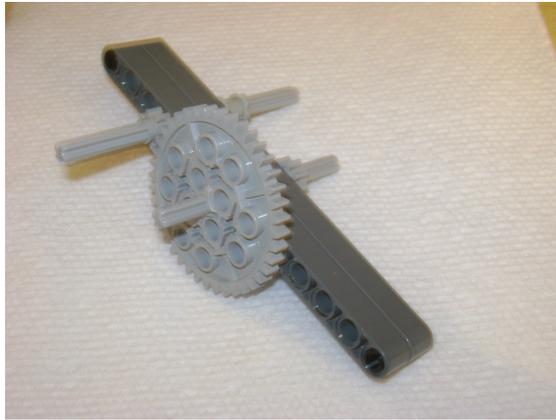


Figure 11. Implementation of Gearing Down Driver and Follower Gears using Lego

Compound gearing is the condition under which gears of different sizes on the same axle are connected to other gears in order to build a more extensive gearing system. The new system can either gear down or gear up a system, or both. Compound gearing gives the ability to construct a system that either changes the angular velocity or the torque or both by adding gears to an appropriate arrangement. In Figure 12 [15], two separate 5:1 gearing down arrangements are shown connected to each other by the axle passing through the first 40-tooth gear and the second 8-tooth gear.

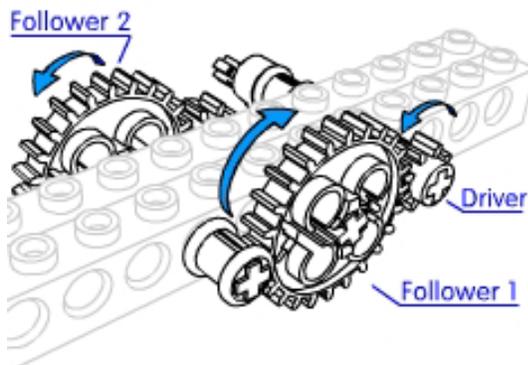


Figure 12. Compound Gearing using a Driver and Two Follower Gears

The first 40-tooth gear turns five times slower than the driver, according to the ratio. The second 40-tooth gear, Follower 2, turns even slower—five times slower than Follower 1. This arrangement increases the gearing down ratio to 25:1.

Idler gearing is the condition used to make a driver gear and a follower gear turn in the same direction. A system consisting of two gears, a driver gear and a follower gear,

turns the gears in opposite directions. A gear placed between the driver and the follower gears will make the driver and follower turn in the same direction without changing the gear ratio. The idler gear rotates in the opposite direction of the driver gear; the follower gear rotates in the opposite direction of the idler; so the driver gear and the follower gear rotate in the same direction. Because the intermediate gear does not affect the performance of the gear train, it is called an idler gear. The idler gear adds spacing between the two end gears. Figure 13 shows the implementation of this compound gearing using Lego pieces. Figure 14 [15] shows an idler gearing, while Figure 15 shows its implementation using Lego pieces.

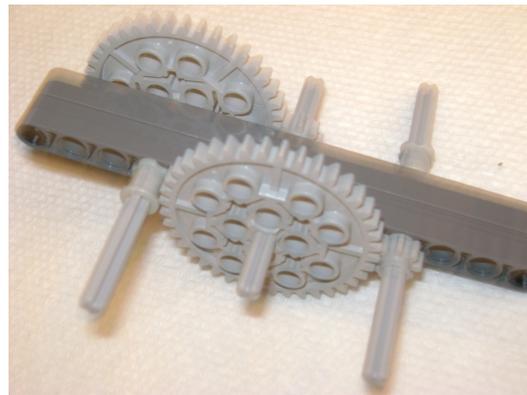


Figure 13. Implementation of Compound Gearing with a Driver and Two Follower Gears using Lego

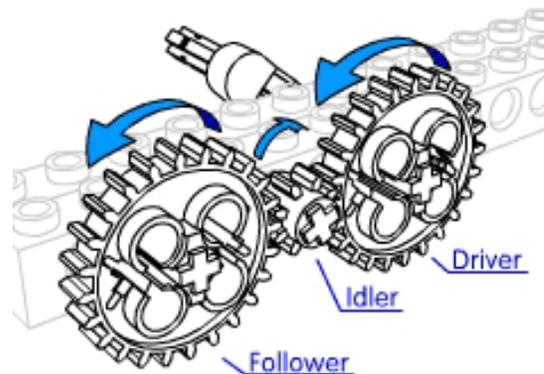


Figure 14. Driver, Idler, and Follower Gearing Arrangement

Consider the example of a simple gear train with a driver, idler, and follower. Let a simple gear train have three gears so that the input gear, G_i , meshes with an intermediate gear, G_i , which in turn meshes with the output gear, G_o . Assume that a proper distance of the shaft has been selected and the pitch circle of the intermediate gear rolls without slipping on both the pitch circles of the input and output gears. This yields the two relationships:

$$\frac{\omega_i}{\omega_l} = \frac{N_l}{N_i}, \quad \frac{\omega_l}{\omega_o} = \frac{N_o}{N_l}$$

The speed ratio of this gear train is obtained by multiplying the above two relationships to obtain

$$R = \frac{\omega_i}{\omega_o} = \frac{N_o}{N_i}$$

Thus, the gear ratio is exactly the same as for the case when gears G_1 and G_2 are engaged directly.

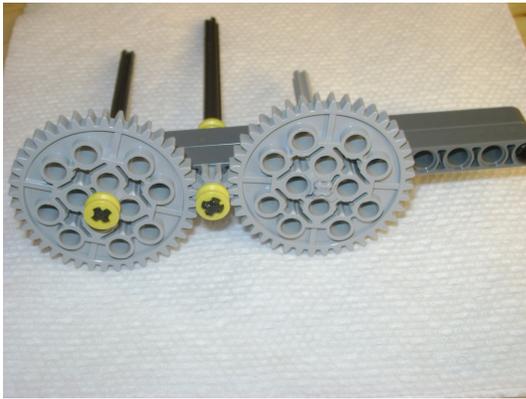


Figure 15. Implementation of Driver, Idler, and Follower Gearing Arrangement using Lego

Bevel gears are spur gears that mesh at a 90-degree angle. Their teeth are formed on conical surfaces. They are used to transmit motion between intersecting shafts. The gear rules developed for spur gears remain the same (see Figure 16). Worm gears have their axes perpendicular to each other, resemble a screw, and act like a gear with one tooth giving large rotational ratios. The direction of rotation depends upon the direction of rotation of the worm and whether the worm teeth are cut right hand or left hand. Worm gear sets are used to transmit rotary motion between nonparallel and nonintersecting shafts. The gear rules developed for spur gears remain the same (see Figure 17). Backlash is the slight motion of a gear when it changes direction of rotation due to the space between the teeth of two gears. When a number of gears are connected in a cascade, the backlash for each one is added and can become quite noticeable. This can be a problem in some applications. Figure 18 exemplifies the effect [16].

Use and Rules of Gears

Gears can be used in various situations during the construction of a robot [17]. A number of typical applications

are presented in Table 3. It is suggested that students study, build, evaluate, and practice these applications in order to master the basics and extend them to more advanced applications.

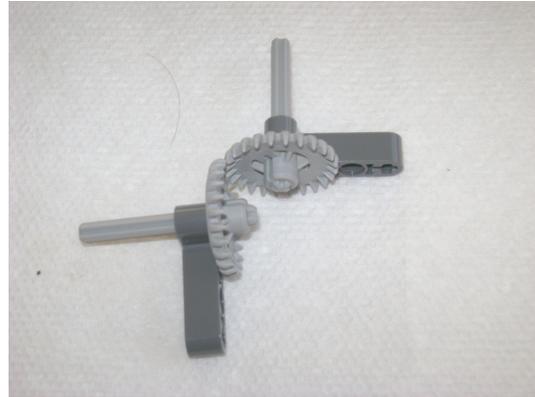


Figure 16. Implementation of Bevel Gears using Lego



Figure 17. Implementation of a Worm Gear using Lego

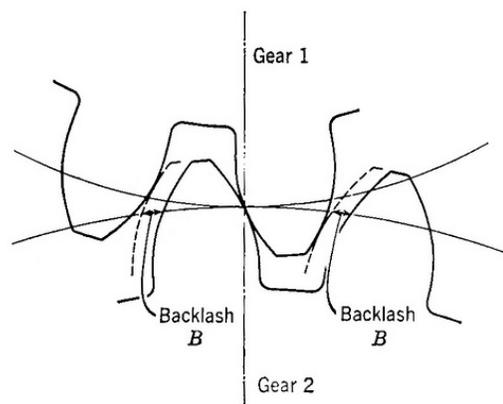


Figure 18. Illustration of the Backlash Effect Between Two Gears

Table 3. Typical Applications of Gears

| |
|--|
| Rotate more than one part using one motor. |
| Rotate a part that is not attached to the motor shaft. |
| Rotate a part at higher or lower speed than the motor's own speed. |
| Rotate a part in the opposite direction of the motor. |
| Transmit torque from one axle to another. |
| Move rotational motion to a different axis. |
| Change rotational motion to linear motion. |
| Keep the rotation of two axles synchronized. |

Table 4 summarizes the basic rules of gears for a student to study, evaluate, and build mechanisms based on these rules. Mastering of these rules will help in their proper application to the construction of complex robots.

Table 4. Rules of Gears

| |
|--|
| Two gears next to each other move in opposite directions. |
| Motion of a driving gear by one tooth moves the gears it is meshed with by one tooth. |
| Gears have different number of teeth. Regular Lego gears have 8, 12, 14, 16, 20, 24, 36, and 40 teeth. |
| The gear ratio of two gears is equal to the ratio of the number of teeth of the two gears. |
| The gear ratio affects the speed of the two gears. |
| The gear ratio affects torque. The faster the gear turns, the lower the torque. The slower the gear turns, the higher the torque. |

Gears: A Lesson Plan

Papert [18] in a presentation entitled "Technology in Schools: Local fix or Global Transformation?" makes the following recommendations: "... support the idea that... the content of the curriculum, the modes of learning and the structure of school are open to re-examination and radical replacement." And, "... supportive conditions for visionary teachers...and join in the launching of a national debate about the future of the learning environment."

In a robotics program environment, the subject of gears should be presented, demonstrated, and practiced [19-21]. Critical and creative thinking are important aspects for the formulation of solutions and selection of the most promising solution and its implementation. A suggested lesson plan is presented to aid in the clarification of ideas, remove misconceptions, and get practical experience.

Gears: Introduce engineering design as a process of solving problems. Statement of the problem, solution, implementation, optimization as applied to gears.

Time Duration: About 50 minutes

Lesson Objectives: Students will explore gears, rules of operations, and assembly of gear systems.

- Types of Gears
- Gear Systems
- Rules of Gears as discussed in Table 4.
- Modeling and prototyping a gear system

Lesson Material: A set of gears (like Lego)

- Recognize gears
- Build gear systems
- Verify gearing up and gearing down.
- Advantages and disadvantages of gearing.
- Gear system analysis
- Gear system synthesis
- Reference material: This paper.

Review Questions

- See in Table 5

Vocabulary

- Definition of terms related with gears: Gear, Gear ratio, Gearing up, Gearing down, Spur gear, Driver gear, Follower gear, Compound gearing, Idle gearing,

Prototyping

- Build each one of the gear types presented. Measure and verify the calculations, and physical intuition. Apply the acquired experience to a theme (i.e., yearly FLL project theme).
- Presentation
- Discussion
- Proposed Solution and selection of one.
- Prototyping and improvement.

Table 5. Sample Review Questions

| |
|--|
| What is a gear? |
| Why gears are used in a robot? |
| What is gear ratio? |
| How do gears work? |
| What kind of gears you are aware of? |
| What sizes of gears you are aware of? |
| What is gearing up? |
| What is gearing down? |
| What is idler gearing? |
| How do you know that your robot needs more torque? |
| How you can increase the torque of a robot? |

Conclusion

The subject of gears, their types, rules of operation, interconnections, mathematical descriptions, various implementation themes, along with pertinent definitions was presented as a means to integrate the disciplines of STEM. This paper adds to the capital of pedagogical knowledge on how tools in robotics education, such as Lego, can be used to foster the integration of various disciplines in a relationship useful in problem formulation, solution, and implementation.

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Biography

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COMPARATIVE ANALYSIS OF STUDENT OUTCOMES FOR A 2+2 TECHNOLOGY MANAGEMENT AND ADVANCED MANUFACTURING BACCALAUREATE PROGRAM

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Bryan Reaka, Western Kentucky University

Abstract

Traditionally, students who graduate from high school have one of two options: workforce training or academics. In the first, students get a job or attend a technical/community college to learn a trade or obtain a vocational degree. In the second, students attend a university and obtain a well-rounded baccalaureate degree. One increasingly appealing option for students is to begin at a community or technical college. Once students complete their general education at the community college, they continue their education by transferring to a four-year institution. This has resulted in the increased development of university 2+2 programs. As four-year institutions continue to add these to their program offerings, the question arises about how 2+2 transfer students perform scholastically.

For this study, the authors compared a traditional four-year degree program in Advanced Manufacturing with a 2+2 program in Technology Management. These two programs were offered in the same department and have 27 hours of required courses in common, as well as the same general education requirements. In this study, the educational experience of the 2+2 transfer students was equivalent to that of the four-year university students. Given the difference in tuition costs between typical two-year and four-year schools for manufacturing and technology students, enrolling in a community or technical college for the first two years is a more cost-effective approach.

Introduction

As the labor market becomes more complex, high school and college students face an array of confusing decisions. This confusion emanates from a lack of understanding on what the future holds in regards to the education and training necessary to achieve their career goals. In addition, the selection of an educational path that will best prepare students for jobs that do not yet exist, or for technology that has not been developed, can be daunting. With all of the uncertainty about career goals, students are left to their own

devices concerning their educational path. Traditionally, students have been given one of two options, workforce training or academics. In the first, students get a job or attend a technical/community college to learn a trade or obtain a vocational degree. In the second, students attend a university and obtain a well-rounded baccalaureate degree.

With the uncertainty of the labor market and what is needed to become successful comes the problem of students attending four-year colleges without selecting a major, or changing majors several times while exploring what they are interested in. With the average one-year cost of public four-year in-state tuition at \$8,244 [1], families find it difficult to finance years of exploration and students are graduating with high educational debt.

One increasingly appealing option for students is to begin at a community or technical college where they can explore degree options while completing the majority of their general education requirements. In some cases, students can also complete some of the advanced courses for a major at a reduced cost. In addition to reduced cost, there are other advantages of a community college over a traditional four-year institution including transferability of credits, convenience, size, schedules, and vocational training programs. Once students complete their general education at the community college, they can continue their education by transferring to a four-year institution. This has resulted in the increased development of university 2+2 programs. As four-year institutions continue to add these to their program offerings, the question arises about how 2+2 transfer students perform scholastically.

Purpose

How do transfer students from community or technical colleges perform in comparison to traditional four-year university degree students? For this study, the authors compared a traditional four-year degree program in Advanced Manufacturing with a 2+2 program in Technology Management. The Technology Management program was a 2+2 program designed specifically for students currently holding

a certificate or associate's degree from a technical school, two-year college, or four-year institution. The program was a capstone program that provided a two-year management emphasis for those working toward a supervisory position in industry. The Advanced Manufacturing program was a four-year program that prepared individuals to apply both managerial and technical skill in advanced manufacturing of industrial operations. These two programs were offered in the same department and had 27 out of 74 credit hours of required courses in common, as well as the same general education requirements. As students assess educational needs in preparation for future goals, is the best path for a B.S. degree in a technical field through a traditional four-year program or a two-year community or technical college with transfer to a completion degree program?

Two hypotheses for the study were postulated. First, there is no difference in the performance of transfer students compared with four-year students, as rated by supervisors in the internship and work experience review sheets. Second, there is no difference in the scores of transfer students compared with four-year students on the ATMAE certification exams.

Since Johns Hopkins University first pioneered the establishment of majors and minors, incoming freshmen have been burdened with the practice of selecting a major. When high school seniors are asked what they want to study in college, they will often respond with degree titles that sound interesting or familiar to them at the time; but ask the same students what they want to do after college and they generally have no idea. "For many students, in fact, the process of deciding on an undergraduate major typically involves making a selection and later changing their minds one or more times before graduation" [2]. Intuitive estimates of the percentage of students changing their majors runs well over 50 percent, but Kramer et al. [3] found the average to be approximately 75 percent.

With the changing of degrees comes added time to complete major program requirements. The U.S. Department of Education's National Center for Education Statistics found that only 36 percent of full-time students who entered a four-year institution graduated from college within four years. After six years, the percentage had increased to 57.5 percent [4]. With the median load debt of borrowers in 2007-08 for a bachelor's degree from a four-year public university at just under \$18,000 [5], the only thing that helps the new college graduate is the guarantee of a high-paying job. Hemmelman [16] reported that "43 percent of young workers with licenses and certificates earn more than those with an associate degree, 27 percent of young workers with licenses and certificates earn more than those with a bachelor's degree, and 31 percent of young workers with associate degrees earn more than those with a bachelor's degree".

The startling fact is that above average wages are a return for occupational skills that are in demand, not education per se. Conversely, in the late 1960s, a "degree essentially entitled a graduate, regardless of major, to a good job and a ticket into the elite society" [2]. However, with fewer jobs available, the particular major a student chooses and how long it takes him to earn a degree, now matters. Although education and earnings are correlated, high wage rates are paid as a premium for specialized skills that are in demand. High skills equals high wage employment. As to why college graduates generally make more money, "By the mid-1990s, of the 1.2 million baccalaureate degrees awarded per year 20 percent were awarded to business majors, while another 58 percent were awarded to occupational majors for example engineering, health sciences, and education" [7].

"To get a better job" is a primary reason entering freshmen give for matriculating into college [8]. Incoming students may believe that, as the number of four-year college graduates grows, a four-year degree will be needed to get even nonprofessional employment. A more likely situation is that college graduates would displace those with lesser degrees, but only in low-skill/low-wage employment; they will not displace those with technical skills.

People believe most jobs in the future will require a four-year college degree. In reality "while the number of jobs that require no post-secondary education has declined, the researchers note that only one-third of the jobs created in the coming years are expected to need a bachelor's degree or higher" [9]. According to former Labor Department Secretary Robert B. Reich [10], "Too many families cling to the mythology that their child can be a success only if he or she has a college degree. Sadly, far too many young people are going to college who are not finishing college and who are finding that what they are being trained for in college has little or no relevance to getting a good job". In fact, over the past thirty years there has been a considerable growth (9.44% in 1970 to 26% in 1999) in the number of Post Baccalaureate Reverse Transfer (PBRT) students attending community colleges "for personnel growth, but more were attending for career enhancement" [11].

According to the National Center for Education Statistics [12], 92 percent of high school graduates in 2004 indicated that they planned to continue their education after high school. Sixty-two percent of the high school graduates planned on attending a four-year institution, while 31 percent planned to attend a technical or community college. However, this statistic does not match the needs for the largest growth in jobs for the future. Through 2016, the largest number of job openings will be in the middle-skill occupations. This field is defined by two characteristics: 1) educa-

tion above a high school diploma, but below a bachelor's degree, and 2) jobs that are not easily outsourced as is the case with low-skilled or even high-skilled professional jobs [13]. The combination of highly skilled technical training with the well-rounded education of a baccalaureate degree is critical in meeting the occupational needs in the U.S., and particularly in manufacturing. With more 2+2 programs combining the highly skilled studies of vocational and technical education with four-year professional and well-rounded management focus, it is critical to ensure that the 2+2 programs are meeting both standards.

Methodology

The authors collected historical data (August 2009–August 2012) from two different sources. One data set was the supervisor review sheets that rated the application of technical and social skills in internships and guided work experiences. The second data set included the results of the Certified Technology Manager (CTM) and Certified Manufacturing Specialist (CMS) exams offered by the Association of Technology, Management, and Applied Engineering (ATMAE). The content of all CTM exams are the same. CMS exam content is also the same. Students in both the Technology Management and Advanced Manufacturing programs take the exact same management courses and the exact same content. A total of 28 Advanced Manufacturing students and 26 Technology Management students completed an ATMAE certification exam. The CTM exam was administered after completion of the capstone experience. Students complete the capstone experience (Senior Research) in the spring semester of their last year.

During the study period, a total of 19 Advanced Manufacturing students and 33 Technology Management students completed an internship or supervised work experience course. At the end of the internship or supervised work experience, the student's supervisor was required to complete an evaluation of each student's work performance. The characteristics evaluated were attendance and punctuality, preparation for the job, quality of work, quantity of work, time management, use of supplies and equipment, technical competence, ability to solve problems, and overall performance. Data were not collected on the dates and locations of the internships. The following limitations were applied to the study.

- The size of the sample was limited to students who completed an internship and the CTM exam.
- Students self-selected their internships and certification exams.
- The internship was not required for Technology Management students.

- There are differences in the types of internship jobs and levels of job difficulty. These differences are somewhat mitigated by faculty who must approve the specific job objectives before students can enroll in the internship/supervised work experience.
- Evaluations by the student's supervisor were job-specific.

The following assumptions were held for the study.

- There is no difference between the Technology Management and Advanced Manufacturing curriculum, content, or applied skill sets.
- Internship evaluations are a valid measure of assessing specific job performance.

Using Excel, the data findings for the internship and exam scores were tested for validity, and equal or unequal variances were applied depending on the test. An independent, two-sample t-test was used to determine if the means of the supervisor's evaluation and the ATMAE certification exams were statistically different.

Findings

The authors were not able to reject the first null hypothesis using an alpha level of 0.05. As shown in Table 1, there was no difference in the means of the four-year Advanced Manufacturing students and the 2+2 Technology Management students in all of the characteristics of the internship or supervised work experience.

Table 1. Independent Two-Sample t-test of Internship or Work Experience Characteristics

| Characteristic | df | t-Stat | t-crit | P |
|-------------------------------|----|--------|--------|------|
| Attendance & Punctuality | 50 | -0.08 | 2.01 | 0.93 |
| Preparation for the job | 50 | 0.20 | 2.01 | 0.84 |
| Quality of Work | 50 | 0.12 | 2.01 | 0.91 |
| Quantity of Work | 50 | -0.03 | 2.01 | 0.98 |
| Time Management | 50 | -0.82 | 2.01 | 0.42 |
| Use of supplies and equipment | 38 | 1.18 | 2.02 | 0.24 |
| Technical Competence | 50 | 0.52 | 2.01 | 0.61 |
| Ability to solve problems | 50 | 0.32 | 2.01 | 0.75 |
| Overall Performance | 40 | 0.75 | 2.02 | 0.45 |

Note. Since the $t\text{-Stat} < t\text{-critical}$ and $*p > 0.05$ in all characteristics, the authors were not able to reject the null hypothesis that there is no difference in student performance as rated by supervisors on internship review sheets.

The authors were not able to reject the second null hypothesis, that there is no difference in student performance of the four-year Advanced Manufacturing (AM) students and the 2+2 Technology Management (TM) students, as scored by the ATMAE certification exams. The results of the t-test are shown in Table 2.

Table 2. Independent Two-Sample t-test of ATMAE Certification Exams

| T-test: Two-sample assuming equal variances | | |
|---|-------------|-------------|
| | AM Students | TM Students |
| Mean | 91.75 | 95.26923 |
| Variance | 494.787 | 352.2846 |
| Observations | 28 | 26 |
| Pooled Variance | 426.2763 | |
| Hypothesized Mean Difference | 0 | |
| Df | 52 | |
| t Stat | -0.62585 | |
| P(T<=t) one-tail | 0.267075 | |
| t Critical one-tail | 1.674689 | |
| P(T<=t) two-tail | 0.53415 | |
| t Critical two-tail | 2.006647 | |

Note. Since the $t\text{ Stat} < t\text{ critical}$ and $*p > 0.05$, the authors were not able to reject the null hypothesis that there is no difference in student performance, as scored by the ATMAE certification exams.

Implications of the Research

In this study, the students in the 2+2 Technology Management and four-year Advanced Manufacturing programs possessed the same technical-managerial skill sets. There was no statistical difference between them in internship performance or ATMAE certification exam scores. The difference was that the 2+2 Technology Management students gained their technical skills at community or technical colleges and their managerial skills at the university, while the Advanced Manufacturing students gained both their technical and managerial skills at the university. Given the limitations of

evaluating student outcomes from an immediate, vocational perspective, the study implied that the educational experience of the 2+2 transfer students was equivalent to that of the four-year university students. Given the difference in tuition costs between a typical two-year and four-year school for manufacturing and technology students, enrolling in a community or technical college for their first two years is a more cost-effective approach. In addition, for those students who may continue to be unsure of a career path or particular major, the two-year schools offer the opportunity for exploration without going into serious debt. Furthermore, students who elect to enter the workforce after one or two years of college can still have job opportunities, particularly in the trades or as technical staff. Thus, the findings of this research study dispel some of the myths associated with the two-year technician and the four-year technologist and their applied skill sets. However, the findings should be perceived cautiously as there is no guarantee of achievement, salary, or career success based on test scores, evaluations or grade point average.

The degrees and skill sets eventually obtained by these two groups were similar and reinforce the value of the technologist and technology manager as a viable career path for young men and women who advance science and engineering for practical use. Future educational models and strategies should include the development of well-designed 2+2 transfer programs between two-year and four-year institutions. In addition, future strategies should consider a secondary education pipeline, transition and transfer support for post-secondary institutions, instructional and course support at all levels, and laboratory resource development for these types of programs. Well-designed cooperative agreements between technical education programs increase visibility, promote first-generation college success, and dispel media-perpetuated myths [14]. Collaborative partnerships between two-year and four-year institutions will transform the technology education pipeline and improve the economic prospects of the future workforce. Future studies could comprehensively describe and test these programs, including, if possible, classroom outcomes, relationship to grade point average, and alumni salaries, especially as the immediate technical skills become outdated.

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LESSONS FROM A RESEARCH AND DEVELOPMENT PROJECT FOR A FIRST-YEAR ENGINEERING COURSE

Matthew C. Carroll, Texas A & M University at Galveston

Abstract

The integration of university-based research into undergraduate engineering programs has for several years been a major focus in engineering education throughout the world. For engineering students, training in research and development has until now been primarily concentrated in the final year of studies. Senior design projects, often called capstone projects, have become almost universal in engineering programs. These nearly always include application of technical material from one or more engineering courses, but often include research, creative design and development, and the written and visual presentation of results to a professional audience as well.

Many engineering students have trouble with these design projects. The trouble is not with the application of learned engineering principles to routine design tasks, but rather with the more creative and open-ended aspects of these challenges, and with the supplemental skills required for making the overall project a success. Examples of these skills would include evaluation of alternative solutions, integration into a project team, procurement of materials, design of experiments, and oral and written presentation of results.

In this paper, the author describes lessons learned from conducting a pilot engineering research and development project for first-year engineering students at Texas A&M University at Galveston. The author believes that it is both possible and necessary to introduce engineering students to research and development issues very early in their engineering studies, and that projects can be attempted for which the level of technical expertise required does not exceed that of the average incoming university student but which, nevertheless, can expose them to all of the essential elements involved in engineering research and development.

Introduction

The integration of university-based research into undergraduate engineering programs has received an increasing focus in engineering education, particularly over the last twenty years. Former president Bill Clinton [1], in announcing his plan for significant increases in federal spending on university research for fiscal year 2001, stated that:

University-based research provides the kind of fundamental insights that are the most important building blocks of any new technology or treatment. It also helps produce the next generation of scientists, engineers, and entrepreneurs. (p.1)

For engineering students, training in research and development has been primarily concentrated in the final year of studies, when the students already have the basic technical competence to accomplish design tasks in their field of study, and are thus able to appreciate the application of engineering theory to real-life problems. Senior engineering students typically have a number of options including senior design projects, done as a group under the supervision of a faculty member; research projects, which supplement the graduate-level research endeavors of one or more faculty members; or, industrial projects undertaken in cooperation with an involved engineering or manufacturing facility.

Engineering students in these senior-year projects often lack preparation for a broader scope of engineering work that includes much more than simply applying information learned in coursework to straightforward design tasks. Atman et al. [2] published a comprehensive study on the evolution of student research and development abilities from freshman to senior year, and compared these abilities with those of a selected sample of 19 expert practitioners. They found that incoming seniors lack preparation in problem scoping, consideration and evaluation of alternative solutions, and gathering of information not readily available from familiar sources. With regard to consideration of alternatives, Newstetter and McCracken [3] noted that even as final-year projects progress, students have a tendency to focus on just one design and try to make it work. Charyton and Merrill [4] noted that general exercise of creativity in approaching research and development has also been understressed in earlier years.

Even more ominous is a study conducted by Genco et al. [5] in which 48 freshmen and 46 seniors were asked to design a next-generation alarm clock. According to a five-point originality metric developed by them, students were scored on a scale of 0 to 10, with 0 representing a common design, 5 an interesting design, and 10 a truly innovative design. Their conclusion was:

Table 1. Summary of ENGR 111 Course Objectives

| Awareness |
|---|
| Orientation to engineering profession, social and environmental responsibility, professional ethics, affirmative action and minority issues, women in engineering, global challenges, integration of engineering into the overall structure of society. |
| Knowledge |
| Design process, critical thinking, technical writing, computer concepts, dimensions and units, introduction to statics and dynamics. |
| Skills |
| Spreadsheet calculations, mechanical drafting, computer-aided drafting (CAD). |

Project Origination and Objectives

Beginning with the 2009-2010 academic year, the author was given responsibility for all sections of ENGR 111, with considerable flexibility as to how both the classroom and laboratory components of the course could be arranged. At Texas A&M University in College Station, the course is taught to all engineering majors, and catalog specifications allow a wide variation of requirements tailored to the specific engineering major. At Galveston, the opportunity exists to actually form inter-disciplinary teams consisting of both engineering and engineering technology majors; this is not normally possible in College Station, where large sections of ENGR 111 specific to one major are the norm.

During this study, several weaknesses similar to those discussed in the introduction were identified with regard to the preparation of engineering students to conduct design projects during their senior year. Many were related to research and development; a few were not. Some of these weaknesses are listed in the following sections, in approximate order of severity.

Teamwork

It was a common misconception among students that demonstrating teamwork skills primarily involved getting along with fellow team members and avoiding conflict. This misconception was probably bred in courses where teams were created to solve problems of a very limited scope; for example, in MASE 216 Principles of Thermodynamics student teams were formed to simply obtain information about a certain type of thermodynamic component and present

their findings to the rest of the class. Many times, one or two team members would dominate and other students, eager to demonstrate teamwork skills, would amiably consent to performing tasks as directed. As a result, a true synergism of ideas and capabilities among team members did not occur. While minimally inimical to a group's ability to perform a well-defined assigned task, this lack of optimal blending of team human resources could completely prevent a team of students from accomplishing a more open-ended and comprehensive objective.

One additional feature of the Senior Capstone Project itself was that the project teams were formed monolithically (i.e., all students on the same team were either MASE majors or MARR majors). Studies by Fruchter and Emery [13] and later by Schaffer et al. [14] have shown that the cross-disciplinary learning required on mixed teams greatly encourages the evolution from individual to collaborative thinking by team members; hence, involvement at the freshman level where majors are still mixed could provide this, where the senior projects could not.

Evaluation of Alternatives

In senior design projects, students generally develop an engineering design or, more generally, an engineering solution for a technical problem. This problem can be posed by a client (why are our castings too brittle at the bottom?) or one that is generally known (a serious need exists today for a wheelchair that can climb stairs). The majority of senior engineering students had not previously been taught a systematic way to evaluate possible design alternatives en route to deciding on a design or solution to propose to the client or to develop for presentation to the general public.

Incorporation of this instruction and training in a crucial research and development area, while not well-suited for subject-matter courses with specific and narrow educational objectives, could much more easily be included in a more general course with a more open-ended project.

Procurement

During the build phase of the Senior Capstone Projects, many students had trouble procuring materials needed to actually implement their designs. Obtaining general supplies and building materials from retailers, hardware outlets, and home improvement stores was generally not a problem, but whenever specialized equipment was needed, students were generally unfamiliar with the outsourcing methods required to obtain it.

...freshmen-level engineering students can develop more innovative concepts than senior-level mechanical engineering students. Specifically, at the University of Massachusetts, Dartmouth, freshman-level students generate designs with higher levels of originality than their senior-level counterparts, without sacrificing technical feasibility from a manufacturing and design perspective. (p.76)

In this case, then, progress through the engineering curriculum actually eroded the ability of students to develop creative solutions to engineering design problems. Historically, there has been significant discussion about requiring engineering students to perform tasks that mirror those needed in senior projects as early as the first year of engineering studies. Baillie [6] published an excellent review of work performed before 1998 in a comprehensive literature survey citing 54 different sources. This review includes discussion of the various approaches to teaching an introductory engineering course, and to implementing design-and-build projects which teach students to work as a team, construct and test a working engineering device, and give oral and written presentations regarding their projects.

Implementation of these first-year design-and-build projects was discussed by Borrego et al. [7] who conducted a study on the diffusion of education innovations into the engineering programs of a large number of institutions of higher education. The study was framed in terms of awareness (how many schools are aware of discussing implementation of a certain innovation) and adoption (how many schools have actually adopted the innovation in their own curricula). It was found that, among all innovations, the inclusion of a first-year engineering project ranked second for awareness at 92%. Only the inclusion of a senior capstone design project ranked higher at 96%. In terms of actual adoption, the first-year project actually ranked higher, at 65% versus 56% for the senior project.

In this paper, the author describes an engineering research and development project developed over a period of three academic years (2009-2010 through 2011-2012) for an introductory engineering course at Texas A&M University at Galveston. The project was for the ENGR 111 Foundations of Engineering I course, and involved about 25% of the overall course grade. In addition to emphasizing teamwork, design, and communication, the students were introduced to research and development issues such as creative brainstorming, evaluation of alternatives in the presence of incomplete information, evaluation of acceptable error and risk, skill in utilizing information from diverse sources, design testing and the iterative processes that ensue when a design does not work as planned, procurement and vendor

selection, and designing tests and experiments to give the information desired. The author believes there are many projects for which the level of technical expertise required does not exceed that of the average incoming university student, but that nevertheless can expose this student to all of the essential elements involved in engineering research and development. The sophistication of the projects from a technical standpoint does not parallel those conducted by final-year students, but the nature of the work conducted is fundamentally similar.

Background

Presently, there is one engineering program and one engineering technology program at Texas A&M University at Galveston. Both are accredited by the Accreditation Board for Engineering and Technology (ABET). The Engineering Accreditation Commission oversees a Maritime Systems Engineering (MASE) program, which prepares graduates for careers in offshore, coastal, and structural engineering. The systems-oriented approach focuses on offshore, undersea, and coastal structures. The Technology Accreditation Commission (TAC) oversees a Marine Engineering Technology (MARR) program. Within this program, a License Option (LO) complements the functions of the Texas Maritime Academy (TMA) in preparing students for United States Navy, Coast Guard, and Merchant Marine responsibilities, while the Non-license Option (NLO) prepares students for other careers in the marine industry.

The course, ENGR 111 Foundations of Engineering I, is required of all students in both the MASE and MARR majors. In some cases, the course is also selected as an elective by non-engineering majors, including those in Marine Science, Marine Transportation, and Marine Administration. The course is a 2-credit course with a laboratory component, and has basic objectives which can be grouped into three general categories as shown in Table 1.

It was noted by Kilgore et al. [8] that the awareness issues mentioned above play an extremely important role in the education of first-year engineering students. Four of the eleven learning outcomes (c, f, h, and j) in the ABET Criteria for Accrediting Engineering Programs [9] and two of the eleven learning outcomes (i and j) in the ABET Criteria for Accrediting Engineering Technology Programs [10] involved these issues, and the necessity for solving engineering programs within a global and societal context have been very widely acknowledged for many years [11], [12]. This realization played a major role in the reallocation of classroom and laboratory time to accommodate the project, as will be discussed in the next section.

Technical Proposals

Most students were unfamiliar with the procedures both for writing technical proposals and for presenting these proposals to a prospective client. A course, ENGL 301 Technical Writing, does exist at Texas A&M University at Galveston and is required for all MASE and MARR majors. However, the real problem seems to be the limited opportunities for the students to apply the knowledge learned in this course to actual engineering endeavors. In many cases, the senior design sequence was the only set of courses where any technical writing or presentation of this nature was required.

Design of Experiments

Many designs and solutions submitted as final work for design projects were not adequately tested. Testing was generally adequate for most-probable conditions, but there was limited knowledge of testing methods for off-design conditions and a general lack of familiarity with multivariate analysis of experimental data. Training in design and analysis of experiments, another important research and development skill, is often incorporated into a quality engineering course. The author has taught or assisted in the teaching of two such courses: MfgE 460 Quality Engineering at St. Cloud State University in Minnesota, and ENGR 310 Advanced Quality Engineering at Lake Superior State University in Michigan. Because of the emphasis on maritime rather than manufacturing applications, a course in quality engineering is not part of either the MASE or MARR curricula.

In this area, lack of knowledge on the part of the first-year students could actually be an asset. For a working engineering device selection of certain parameters that would be obvious to a student more mature in engineering analysis might require a more empirical approach on the part of a first-year student. The presence of many variables for which value selection is not entirely obvious necessitates a creative trial-and-error-type approach that at least gives the student an opportunity to learn some of the qualitative aspects of these experimentation skills.

Objective Clarification and Problem Scoping

Senior-project teams are selected between the junior and senior years, and assembled around a given engineering problem objective. The overall objective and initial scope of the project is usually determined by the faculty, often in consultation with one or more industrial partners. Students

are then required, very early in the fall semester, to limit and refine this scope as necessary to accommodate both external and internal limitations such as budget, time required, extent of previous work on this problem, and so on. Students generally demonstrate competence in performing this function at a "Scope Presentation", conducted several weeks into the fall semester. One frequently occurring problem, however, is that the project is not considered in a broader context. What is the impact of this project on society? Are there ways to do this project that are more ethical than others? What steps have been taken to avoid harm to humans and/or wildlife?

Do first-year students have the capability of including these issues in their determination of the overall scope of an engineering design problem? Certainly, according to a previously mentioned study conducted by Kilgore et al. [8] in which 124 first-year students were asked to determine factors important to solving a Midwest flooding problem [8]. Hence, inclusion of requirements to include a broader societal context into a scope of an assigned design-and-build project would be beneficial as well.

Student Outcomes

Based on the six issues noted above, the author made a decision to create and implement a design, research, and development project that would replace the set of laboratory exercises and smaller drafting projects previously conducted in ENGR 111 Foundations of Engineering I. This project would be an inter-disciplinary team project that would encompass most of the design and analysis functions commonly found in first-year design activities, but would also include research and development elements that would serve as precursors for later engineering work, especially during the senior year. An attempt was made to include activities such as systematic evaluation of design alternatives, procurement of equipment and materials, preparation of formal technical proposals, and development of test plans. Objectives for the project were developed as listed in Table 2.

The first objective supports the overall course objective of providing students with an introduction to the engineering profession. It is the second objective that is unusual among first-year projects and addresses some of the educational needs listed above. Desired outcomes based on these objectives are listed below.

Upon completion of the project, students will be able to:

- (1) describe clearly the steps involved in designing a product or a solution to an engineering problem and

the additional steps involved in implementing this design;

- (2) function effectively on a design team with fellow students in such a way that the ideas and capabilities of the individual team members are combined in an optimum manner;
- (3) write a detailed set of engineering specifications for a product or a solution based on input data from a prospective client;
- (4) systematically evaluate design alternatives as they relate to these engineering specifications, also taking into consideration factors such as product safety, social and environmental responsibility, and the availability of necessary resources;
- (5) procure the materials and equipment necessary to implement the proposed design or solution, by using, in addition to visits to local retailers, information from business registers, trade journals and catalogs, and electronic sources;
- (6) prepare a technical proposal recommending a given design or course of action to a prospective client and orally and visually present this proposal;
- (7) construct a device based on the selected design and perform on this device preliminary testing, both for normal and off-design conditions, and final testing in the presence of the client; and,
- (8) prepare a final technical report in a standard engineering format, describing fully all aspects of the project, including device design and implementation, testing results, and principles of device operation.

It can be seen that Outcomes (1) and (3) primarily address the first objective, whereas outcomes (4) through (8) address the second. Outcome (2) clearly addresses both objectives.

Table 2. ENGR 111 Project Objectives

| |
|---|
| Engineering Orientation |
| Students will become acquainted with all aspects of the engineering design and implementation process, and will receive a "hands-on" orientation to the types of work required in the engineering profession. |
| Research and Development Skills |
| Students will be exposed to the basic activities and skills involved in engineering research and development, and will begin to acquire these skills. |

Procedure

The first of the semester projects was undertaken during the spring semester of the 2009-2010 academic year. At that time, 46 students were enrolled in three separate laboratory sections of the ENGR 111 course but were combined into a single classroom section. Most students were in their first year of engineering studies, but some had sophomore or junior status, usually because of transferring from another institution where a similar course was not offered.

Two major decisions were initially made:

1. The project was to be a group project: students were divided into nine design groups, with about 5–6 students in each group. Bonding with fellow students assigned a common task in one or more courses proved to be a significant factor affecting student satisfaction with their first-year college experience, even more than faculty advising and mentoring, according to a study by Meyers et al. [15]: "Further, student-student relationships have been recognized as the largest influence on student satisfaction with several college environments with student-faculty relationships as the second-largest influence...". This is consistent with earlier findings of other studies [16–18].
2. The project was to involve the actual building of a working device: for this first semester, the device was a tennis ball catapult, with the Evaluation Day requirement that this catapult fire a tennis ball to hit a garbage can lid at two distances between 10 and 40 feet, selected randomly on Evaluation Day.

Previous projects in ENGR 111 involved designing a device, but not building it. The requirement for the actual construction of a working device was not only necessary to meet the procurement and experimental design and testing outcomes mentioned above, but also instrumental in aiding student self-efficacy beliefs as the students experience tangible success based on their own knowledge and efforts. This type of success is listed as the single most important factor affecting student self-efficacy beliefs in a study conducted by Hutchison et al. [19]. Another interesting point: team bonding, as discussed earlier, was also found to be an important factor.

In subsequent semesters, several other devices with varied Evaluation Day requirements were also featured. A summary of these is listed in Table 3.

Table 3. Selected ENGR 111 Project Devices and Requirements

| Device | Requirements |
|----------------------|--|
| Tennis Ball Catapult | Hit a garbage can lid three times at each of two randomly selected distances between 10 and 40 feet. |
| Mid-air Collider | Two groups cooperate in projecting identical items that collide in mid-air at distances from 10 to 80 feet. |
| Horizontal Injector | A tennis ball or golf ball is projected as straight as possible down a horizontal ramp, and must pass between 2 posts. |
| Sewer Pipe Missile | Modification of tennis ball catapult: tennis balls must be dropped into a barrel about 50 feet away. The barrel replaces a "sewer pipe" that was the intended target until university maintenance removed it!! |

One problem, of course, was the narrow scope of the Evaluation Day requirements, in that an authentic requirement posed by industry was not present. In a recent literature review of over 50 journal articles on project-based and problem-based engineering education, Puente et al. [20] addressed this question: How essential is "task authenticity" in accomplishing educational objectives in a project? Their conclusion was that authenticity is valuable in teaching several skills, including redefining constraints, exploring alternatives, scoping user requirements, and overall reflection on the design process. However, in most other skills, artificial requirements actually proved more effective in accomplishing educational outcomes because their limited scope put design activities such as definitive modeling, evaluation of assumptions, and developing a testing and measurement strategy within reach.

The project was to be a 14-week project, commencing the second week of classes, and ending with "Evaluation Day," on which each design group subjected their device to final testing and evaluation. The submission of the final technical report followed a few days later. Evaluation Day was scheduled during the final examination period, and the event was conducted on the drill field directly east of the Powell Marine Engineering Complex (PMEC), where most of the engineering offices, classrooms, and laboratories are housed.

Figure 1 shows the progression of activities in the project and the weeks in which these activities were performed. Note that there was a significant delay between the Week 2

classroom period, when the research and development project was introduced, and the Week 6 classroom period when the student groups first met.

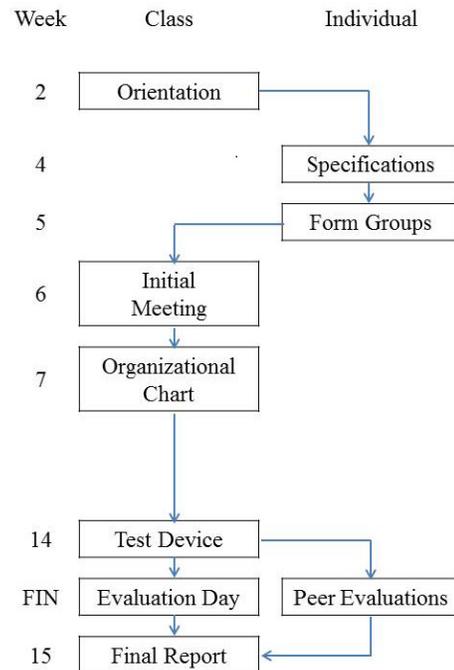


Figure 1. Project Schedule Diagram

This type of delay for projects of this nature is encouraged by Baillie [21], who described four major steps in the creative process. In the first step, the problem is formulated and requirements are defined. The second step involves a "generation phase" and the third an "incubation phase", wherein various possible solutions are generated and then evaluated. Baillie suggests that a "postponement of judgment" facilitated by additional time renders the brainstorming process more effective and results in the establishment of a greater number of "idea pathways" toward a creative solution. Additional encouragement was provided by a requirement that the students establish and submit specifications for the device during Week 4. During an in-class exercise, the students developed a set of engineering specifications for this catapult. These included general, qualitative, and quantitative specifications as well as device limitations and additional characteristics such as cost. Some limitations were that the device could be mechanical or electrical in nature, but was to contain no sharp edges or explosive or chemical components. The students were then allowed to discuss these specifications with other students and modify them appropriately before submitting them the following week.

Group formation commenced during Week 5. A mixed approach was used, whereby some students could form their

own groups but they had to make the effort to formally request their incorporation as a group with justifying reasons. For the remainder of the students, the author used a much more mundane and obvious consideration: what kind of device did they want to build? A trebuchet? A pinball-type device? Maybe an air cannon? This worked well all semesters, and might be a viable alternative to a structured group-formation approach as advocated by Borges et al. [22]. They developed a questionnaire for students aimed at identifying student behavior in regard to team integration in solving a design problem, and then placed the students to ensure a maximum amount of profile heterogeneity within groups.

Once the groups were formed, they all participated in an initial meeting held during the last half of the Week 6 class period, and were charged with developing and submitting an organizational report, which consisted of an organizational chart, a job title and description of duties for each student, and contact information such as telephone numbers and e-mail addresses. Groups were required to appoint a leader, who was called anything ranging from Project Manager to Chief Operating Officer, and a treasurer, charged with the responsibility of ensuring that each student bear an equal share of the project cost. Beyond that, students were free to design their own organizational structure.

Design groups then had a 7-week period to design and build their device. Several activities took place during this period, although the activities for the individual groups were staggered in accordance with individual group needs. Sometimes groups presented a design proposal where the author assumed the role of a reviewer from an imaginary client company. The accompanying oral presentation was to be supported by appropriate visual aids, and students were subjected to questioning by the prospective client.

Classroom instruction during this period included an orientation on procurement and subcontracting, which included information on the use of business directories, trade journals and catalogs, the internet, and local publications such as those disseminated by a chamber of commerce or economic development council. During a few semesters, a hands-on orientation on experimental design and device testing was also given using a device constructed by the author or a device from a previous semester. Some groups had finished work on their catapults by this time and actually brought their devices to the device testing orientation.

During the Spring 2010 Evaluation Day, design groups placed their tennis catapults on or near the edge of the sidewalk adjacent to the drill field. Two distances were randomly selected and a garbage can lid was placed directly in front of each catapult at that distance from the baseline. Each

group was required to adjust their catapult so that it would project a tennis ball and hit the lid. There were three trials at each distance, and a score of 0-25 points was awarded for each trial. A maximum of 25 points was awarded for a direct hit on the lid. In the event of a miss, one point was subtracted for each foot of distance between the impact point of the ball and the lid. Trials where the ball missed the lid by 25 feet or more were awarded a score of 0. Scores for each of the six trials were added to obtain the final score. Students with the winning catapult (i.e., the catapult with the highest final score) were treated to a pizza party; for all groups, this performance score was weighted heavily in the determination of the final project grade.

During subsequent semesters, proceedings were similar and depended on the device being tested and on Evaluation Day requirements. Figures 2–4 depict some of the devices constructed:

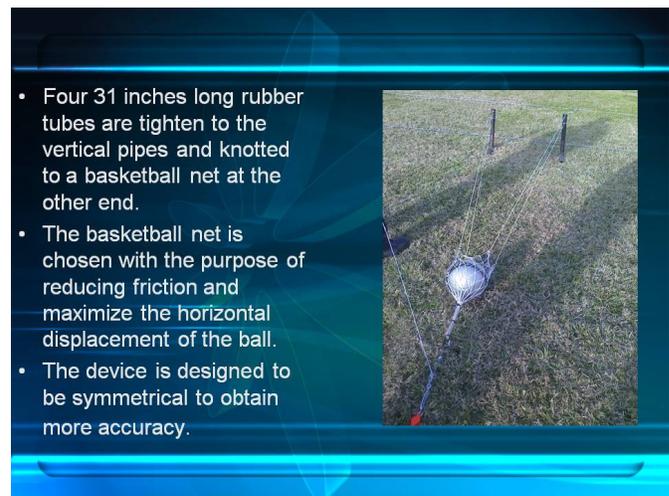


Figure 2. Mid-Air Collider Fall, 2010

Immediately following the Evaluation Day proceedings, students were given a Peer Evaluation Form by which they were required to evaluate each member of their team. On a simple 1 – 10 scale, with 10 the best, students rated the overall competence (on one scale) and effort level (on a second scale) of their fellow team members. There was also a special box to check if, in the opinion of the student filling out the form, a team member did not contribute at all to the overall functioning of the team. Students were also asked to add special comments concerning any team member who went beyond normal levels of effectiveness and/or effort in accomplishing team objectives.

On the basis of these evaluations, students were assigned a “multiple” ranging between 0.8 and 1.2, applied to their project score, which ranged from 0 to 200. For a multiple of

1.1, at least two fellow group members needed to indicate exceptional performance for a student; if all group members indicated this, the student received a multiple of 1.2. In the other direction, the actual scores could be used. These varied somewhat between semesters but, in general, an average less than 5 on scores from all group members resulted in a 0.8 multiple; in borderline cases, members of the group were consulted and the student was sometimes given a 0.9 multiple. In extreme negative cases, when two or more students checked the “no effort” box for a student, the team was consulted and the student assigned a multiple lower than 0.8. In most cases, a student had essentially dropped out of the project and was, hence, assigned only a small amount of credit for work completed.



Figure 3. Tennis Ball Catapult Spring, 2010

Values for the multiple, ranging from 0.8 to 1.2, were compared to those assigned in a similar peer-evaluation approach taken in Australia by Neal et al. [23]. For this project, the peer-evaluation form was more complex, involving six separate questions. Nevertheless, multiple values here also generally ranged between 0.8 and 1.2, and extreme multiples were rare, with only two multiples assigned outside the range of 0.5 to 1.5.



Figure 4. Sewer Pipe Missile (Air Cannon) Summer, 2011

The project was concluded by submission of a Final Technical Report, due at the end of Final Examination Week. Included in the report were specifications developed by the group as a whole, a device description, and accompanying technical drawings. One facet of this report involved a “comments and lessons learned section” which is discussed in more detail in the following section.

Results

Perhaps the most surprising aspect of the entire project was the ability of the students, many of whom had never engaged in a project of this nature, to construct devices that accurately performed their prescribed functions. In the case of the tennis ball catapults, nearly all groups were able to design and build tennis catapults that projected the tennis balls to within a few feet of the target for all six trials. Horizontal injectors were able to project golf balls or tennis balls down a long ramp and through the guideposts as required more than 50% of the time. Most mid-air devices were able to cause identical objects such as soccer balls or beach balls to collide at distances of 40–50 feet. And, the dramatic deposition of a tennis ball, a “sewer pipe missile” so to speak, into a barrel from a firing device nearly 100 feet away occurred on occasion, resulting in loud cheers from all of the students.

Another interesting result of the project was the huge variation in design types. Lack of originality certainly was not a problem. Devices included spring-loaded seesaw devices, crossbows, spring-loaded pinball shooters, and even an air-powered cannon capable of projecting tennis balls up to 300 feet! Some devices were easier to operate than others. Many students started with wildly imaginative design concepts

which, and at some point during the construction of the devices, collided with the engineering realities of material limitations and difficulties in device control. As a result, one group added the following rather blunt comment to their final report [24]: “To conclude, these mini-disasters made us aware of the fact that a good idea on paper or in one’s brain is not necessarily a useful design in the real world.” Yet these realities were not enough to limit the proliferation of designs, and it was certainly concluded that there is more than one way to build an engineering device to meet specifications.

During the project, students experimented with various organizational structures and it was found that a functional structure was most effective in accomplishing the desired mission. Each student was assigned particular duties, and her or his title generally reflected those duties. Aside from the group leader, who was generally designated "Project Manager" or "Design Team Leader," commonly used job titles were:

- Recorder - responsible for editing and submitting reports.
- Tester - responsible for testing the device and determining control settings for each possible distance.
- Builders - charged with actually building the device.
- Personnel Director - in charge of arranging meetings, contacting group members, and ensuring that each member was performing assigned duties.
- Treasurer - responsible for keeping receipts and determining reimbursement for costs at the end of the semester.

Learning the practical aspects of working as a team was one of the more rewarding aspects of the projects for many of the students. During the fall, 2011, semester mid-air collider project, one student from the Palladium design group (design groups were generally named after elements) wrote [25]:

There were many lessons that I learned throughout the course of this project that I know will be helpful in the future. The most important was that teamwork is the only way to succeed with a group project. Although at the beginning we tried to assign separate jobs and have every person work on their own part, in reality what happened was that we ended up working together on everything, sharing ideas and fixing each other’s mistakes. (p.9)

During device testing, students also discovered particularly with the tennis catapult and sewer pipe missile projects, the advantages of a device with one controlling variable.

With an average of 30 settings for this controlling variable, and a minimum of three trials per setting, about 90 trials needed to be conducted. For devices with more than one controlling variable, however, testing requirements were prohibitive (under the assumptions given above, 2700 trials would be needed for a device with two controlling variables and 81,000 trials for a device with three). As a result, most groups initially designing a device with two or more controlling variables modified their devices to operate on a single controlling variable by the time the devices were tested.

In two areas, the project did not proceed as well as expected. Because the required projects were not technically advanced, students were able to obtain needed supplies and equipment from local retailers, and had neither the time nor the inclination to utilize the more advanced procurement methods presented in class. Groups that designed and built the air-powered cannons and needed an air compressor, for example, were usually able to borrow one from a relative of one of the group members.

The other difficulty stemmed from the artificial nature of the project objective; namely, that the "client company" and "client objective" were simulated rather than real. Hence, the students did not experience the dynamics of dealing with a real client. This was discussed earlier, but it is additionally noted that several researchers have concluded that solving a design problem posed by real people in a real context probably contributes significantly to the overall educational experience. Daly et al. [26], for example, in a recent study discussing the experiences of design professionals stated [26]: “...if that same problem is viewed as a design problem, a problem with real context and real people, with have objective and subjective ideas about the qualities of good and bad designs, the task is likely to be approached differently.”

Zoltowski et al. [27] also stressed the importance of the “human-centered” element in design and made several suggestions as to the incorporation of “human-centered design” into the educational experience. Perhaps a future project can be selected for which the level of technical expertise required is not inappropriate for first-year students, yet is still useful to a segment of local industry.

Conclusion

It can be concluded, then, that the project objectives were met, although additional project development and modification are needed to address the two weaknesses mentioned above. Students did receive serious training in research and development aspects normally beyond the scope of an introductory engineering course, and exhibited remarkable capabilities for designing and building devices that performed

according to specifications. One student summed up his learning experience as follows [28]:

From this engineering project I learned how to work as a team to coordinate between the building and design processes of a design project. I learned how to work with metal in the machine shop, put proper calculations on paper for practical purposes, and how to schedule meeting times in a group setting. This project really helped me know what is involved in engineering design. I believe that my experiences here will help me in the future when I'm working under the management of an engineering firm and need to complete a project by a deadline. Eventually, the leadership and time management skills I learned will help me run my own engineering firm. (p.11)

Additional research would certainly need to be conducted to determine whether students developed skills that made them more effective in Senior Capstone projects. Some of the students that completed the Spring 2010 and Fall 2010 first-year projects are now in their senior year and, thus, data can be collected comparing the success of these students with those going before them. Furthermore, an analysis of the impact of this project on graduation and retention rates would be highly beneficial and, as the 2013-2104 academic year progresses, some data should become available for this.

Acknowledgments

The author wishes to express his gratitude for the support and encouragement he received from his faculty and staff colleagues in the Departments of Maritime Systems Engineering and Marine Engineering Technology at Texas A&M University at Galveston, and for the highly diverse, intelligent, and motivated group of students that made the implementation of this project such a rewarding experience. He also wishes to acknowledge a number of references not specifically cited in this work that, nonetheless, contributed to the author's overall understanding of the process by which engineering students learn research and development principles and skills [29–36].

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Biography

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THE DEVELOPMENT OF A YOUTUBE CHANNEL FOR ENGINEERING AND ENGINEERING TECHNOLOGY INSTRUCTION

Mark French, Purdue University

Abstract

A YouTube channel was established to assist engineering technology students by hosting sample problems for their classes. YouTube is a website originally intended to allow people to easily share videos with one another and has quickly become one of the most popular sites on the Internet. It is a popular source of educational information, including lectures and sample problems on a wide range of subjects. The channel has attracted viewers worldwide and a total of more than 1.9 million hits to date. It also has one video that has gone viral.

The success of this channel appears to be due, at least in part, to the short, specific nature of the videos and the ease with which new videos can be produced. The comment features on YouTube assist by allowing immediate feedback so that viewers can ask for more videos and indicate which videos are most helpful. Accumulated data show that many viewers report themselves as being more than college age, even though the viewing patterns are closely linked with traditional academic calendars. Viewers also report themselves as being overwhelmingly male.

Introduction

YouTube and similar websites are being widely used by educators as a way of reaching students outside the classroom. It is very easy to start a channel, and there is no cost, so it is a very accessible venue for teachers who seek another way to reach their students. A quick search shows that instructional videos currently available range from basic ones in which teachers have simply recorded lectures to very elaborate ones that use graphics, demonstrations, and significant post-processing. As a result, a generation of students is growing up having turned to YouTube for information on a wide range of subjects [1].

One only needs to look through YouTube to see that many teachers are posting educational videos. They range from short, specific videos of the type described here to longer ones that are essentially complete lectures. Some are attracting a large number of viewers and it is not uncommon to find individual videos with more than 10,000 hits.

In this paper, the author describes the development and growth of a YouTube channel (www.youtube.com/user/PurdueMET) that has been successful in reaching engineering and engineering technology students worldwide. The videos are short – usually between 8 and 12 minutes long – and generally focus on the solution methods for specific problems in engineering and engineering technology.

Background

The role of social media in general, and YouTube in particular, has become the subject of investigation by researchers in a variety of fields [2], [3]. YouTube is particularly useful as a resource for instructors wishing to augment the classroom experience by posting videos of lectures [4]. Research and personal observation both clearly show that students are routinely using YouTube and other sites as learning resources [5], though the research on what approaches are most effective is clearly ongoing [6]. One of the most heavily used educational sites is Khan Academy (www.khanacademy.org), a site devoted to short, educational videos.

One distinction sometimes made for videos is whether they are intended for receptive viewing or problem-based viewing [7]. Receptive viewing assumes the students interact in a relatively passive manner and the videos may cover broad topics. Conversely, problem-based videos are directed at specific procedural problems. The videos described here are almost all problem-based. Emerging research is showing that YouTube is an effective tool for procedural learning [8]. One of the more useful elements of YouTube is the ability of viewers to post comments. The comments are visible both to the creator of the channel and other viewers. As a result, they form a means of discussion that can be very instructive [9]. Comments may take the form of questions regarding the videos, but the majority of them have been positive comments regarding their instructional value.

Development of YouTube Channel

The author started a YouTube channel in December, 2009, after trying to record lectures in an undergraduate strength of materials class composed of 73 students. Several

attempts at recording class lectures were not very successful; the resolution was too low to read the board and students didn't really need to see the entire lecture. After it became clear that recording class lectures wasn't working, several students in the class asked for short videos, each showing how to work a single problem. The first video was about 10 minutes long and showed how to calculate the area moment of inertia of an I-beam. Very quickly, it was clear that the video had collected more hits than just the two sections of strength of materials could have generated. More videos on problems in strength of materials were posted and the number of hits grew. One of the first e-mail comments was from a viewer in Austria, so it was clear from the beginning that the videos were reaching a wide audience.

The very simple production process allowed videos to be added relatively quickly. YouTube allows viewers to vote on videos by giving them a 'thumbs up' or 'thumbs down'. Such immediate viewer response, along with hit counts, makes it easy to tell which videos are effective in meeting student needs. Part of the success seems to be due to the format. The videos are typically about 10 minutes long and cover a single specific subject. They generally include details of calculations, including intermediate steps. Since they don't need to fit into a scheduled class period, there is no problem with going through every step in the solution. Viewers who don't need the detail can fast forward, as needed.

The value of this channel was to augment classroom lectures and traditional course material in engineering and engineering technology classes. It was clear from user comments forwarded through the YouTube channel and comments from my own students that they search through the channel looking for videos on specific problems. When a needed video is found, they use it as an example from which to study. Furthermore, it is instantly available whenever and wherever they have web access.

Video Production

The original setup was very simple and is still essentially the same. There was an inexpensive video camera set on a very small tripod on a bookshelf in my office and pointed at the whiteboard. There was not enough light from the fluorescent fixtures, so additional lights were needed. Currently, the lighting setup uses two compact fluorescent photography lights on simple stands. A set of two can be purchased from Amazon or a photo supplier for about \$250. The current configuration was a set of Cowboy Studio 2275 lights. Figure 1 shows a shot from one of the videos.

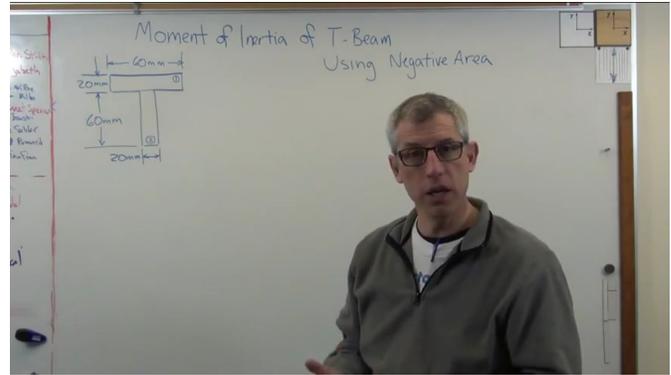


Figure 1. Screen Shot from a Representative Video

For most of the videos, audio just comes from the microphone on the camera. Volume was not high, so a wireless microphone was added. Again, the cost was very modest. There were opportunities to add sophisticated graphics to the videos, and it was certainly tempting. However, a major part of the utility of these videos was their immediacy and the ease with which they could be produced. Detailed graphics, while certainly appealing, greatly add to the time required to produce a video. The result would be fewer, but nicer videos. The viewer community has not requested graphics, but they do routinely request new videos.

Going Viral

Recently, one video went viral and the nature of the viewer community for that video proved to be very different than for the others. The author, working with two Ph.D. students, developed a device capable of shooting a Ping-Pong ball at supersonic speed. It was the development of an older, subsonic device that was in use for more than 10 years as a way of teaching physics and engineering [10]. The supersonic version could shoot a ball through a Ping-Pong paddle and promised to be more compelling.

As a routine matter, a short paper on the new device was posted onto ArXiv [11], an open website where preliminary papers, not having been previously reviewed, can be posted for review. There was no attempt to publicize the paper or the device it describes. However, shortly after the paper became available, there was interest from the press, mostly those writing for websites. Over the next week or two, several organizations sent video crews and reporters, and others conducted interviews remotely. Partially in response to this interest, a video was posted to the YouTube channel. It is typical for videos on this channel to collect a few hundred hits in the few weeks after they are posted. This video attracted about 500,000 hits in the week after it was released. The web allows information to spread very rapidly; videos

or websites that attract large numbers of hits very quickly are referred to as going viral. In extreme cases, viral videos can exceed 10 million hits.

In the two weeks following that video, a few more videos were posted, including one with several high-speed video clips showing the device in operation and impacts on several different targets. A month after the initial video was posted, the videos on the supersonic Ping-Pong gun had collected about 700,000 hits. The nature of the web is that an article or video on one site is referenced by other sites and sometimes copied by other sites. A Google search using the key words ‘supersonic ping pong’ resulted in as many as 16 pages of hits referring to this effort.

One notable effect of the rapid popularity of the Ping-Pong gun video is the nature of viewer comments. For all other videos, the comments were generally respectful and generally positive. Many viewers were encouraging and questions were generally the result of a clear effort to understand the material. Many of the questions were on details of calculations. Additionally, there were regular suggestions for new videos. Comments on the Ping-Pong gun videos were much more varied. Many were positive, but suggestive of little underlying understanding. Many others were negative or dismissive. Along with the increased attention came increased criticism, much of it poorly considered and poorly informed. The numbers of comments and ‘thumbs up’ or ‘thumbs down’ votes greatly exceeded the typical video, though they didn’t scale with the viewing numbers.

Usage Data

YouTube provides detailed usage data that can be used to get a clear picture of who is using the videos, which ones are the most popular, and where the viewers are. Since these videos are informational rather than for entertainment, the number of hits and their sources was being used here as a proxy for their perceived value as an educational tool. The most basic data consisted of “number of hits per day”. There was a clear pattern to the daily hit counts that tracks the school year. Figure 2 shows daily page hits for the YouTube channel from the start of the channel up to the time right before the viral video. On a linear scale, accommodating the page hits for that video would flatten the rest of the graph. Vertical grid lines are 90 days apart.

Different schools end their school years at slightly different times, so hit rates peak in April and taper off to a minimum in June. Conversely, the Christmas or year-end break is observed at about the same time everywhere. As a result, hit rates drop off rapidly in December and start rising again in January. Hit rates tend to grow throughout the semester.

Another trend visible in the data shown in Figure 2 is a high-frequency oscillation. Close examination shows the oscillation to have a period of seven days. This suggests that there are certain days in the week during which students are more likely to view videos as they do their homework. It is difficult to tell which day of the week this would be since there may be a slight delay in YouTube posting hit numbers. It is worth showing the cumulative hits on the channel, including the viral video. Figure 3 shows the cumulative total on a semi-log plot. The bump due to that video is clearly visible in the middle of February.

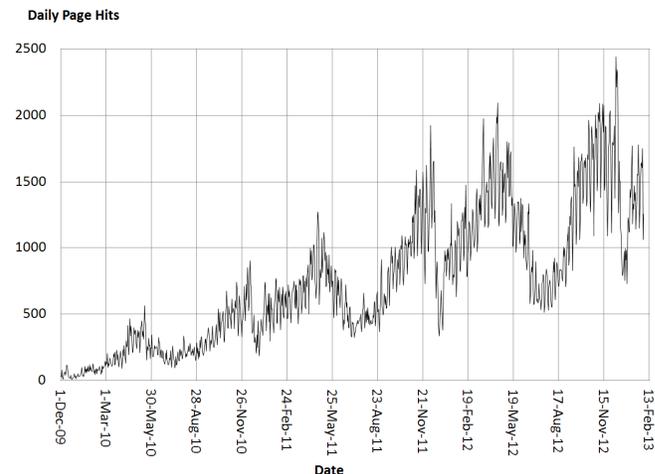


Figure 2. Daily Page Hits on the YouTube Channel

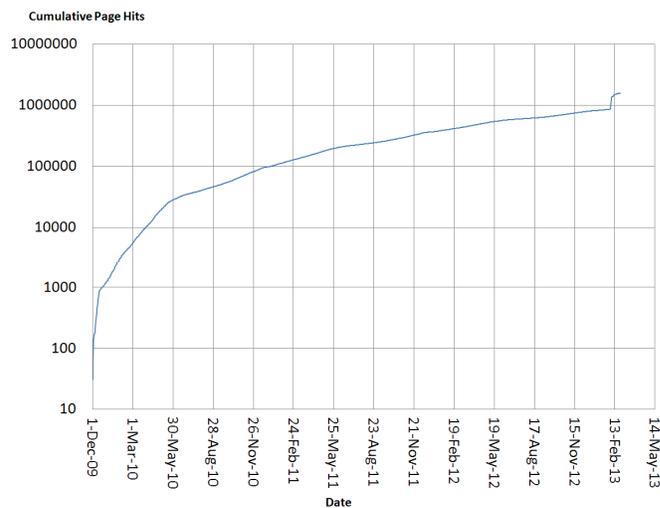


Figure 3. Cumulative Page Hits

In September, 2012, YouTube started estimating total minutes watched (see Figure 4). Since people may not watch a complete video, this may be a useful number. At this writing, there is an estimated 2.6 million viewing

minutes since tracking started. This corresponds to 43,500 hours or almost 22 work years.

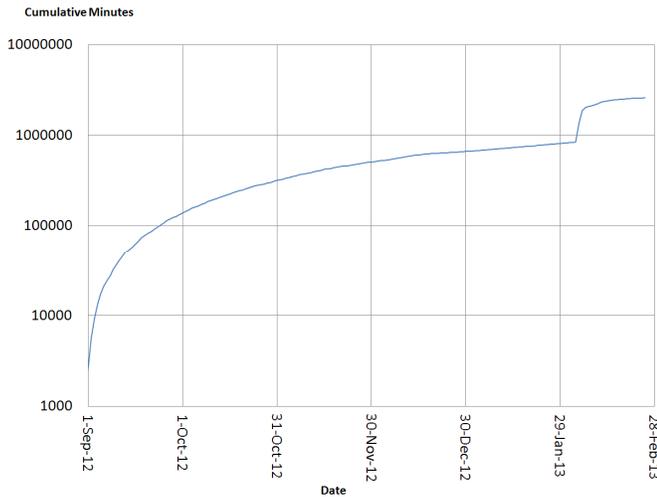


Figure 4. Cumulative Minutes Watched

YouTube users can self-report age and gender. Figure 5 shows age and gender distribution up until the viral video was posted. It is perhaps unsurprising that a large majority of viewers are male; this corresponds roughly to the overall gender distribution of engineering and engineering technology students. Of more interest is the age distribution. More than half of the viewers report themselves as being 35 years old or older – much older than the traditional college student. There are several possible explanations. It is possible that users are not reporting their true ages. It is also possible that ages are being reported accurately and a disproportionate number really are older, suggesting that the channel is being used by practicing professionals as well as students.

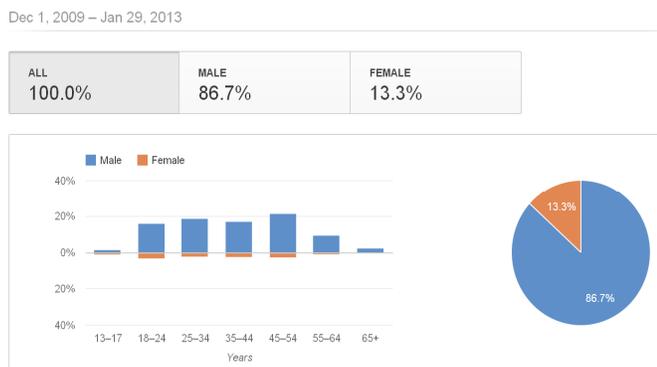


Figure 5. Age and Gender Distribution up until Viral Video

Figure 6 shows the age and gender distribution for the entire lifetime of the channel, including the viral video. The gender distribution is noticeably skewed toward male view-

ers. Viewers of that video report themselves as being 93.2% male. The addition of the viral video also changes the age distribution, though perhaps not in the way one might expect. The age distribution was shifted up rather than down, as one might expect of a video whose intended audience is composed of students. It is also clear from usage data that viewers are found all over the world. Figure 7 shows the countries from which there have been more than 14,000 page views. It is not surprising that the first four countries have large English-speaking populations. However, some apparently unlikely countries like Brazil, Lithuania, and Bulgaria appear on the list. Viewers have been reported from a total of 210 separate countries.

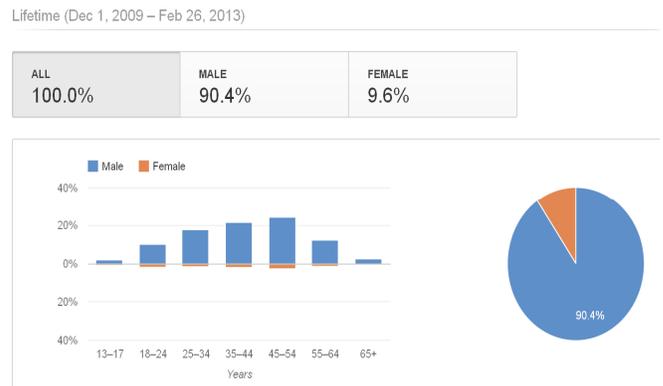


Figure 6. Age and Gender Distribution over the Lifetime of Channel

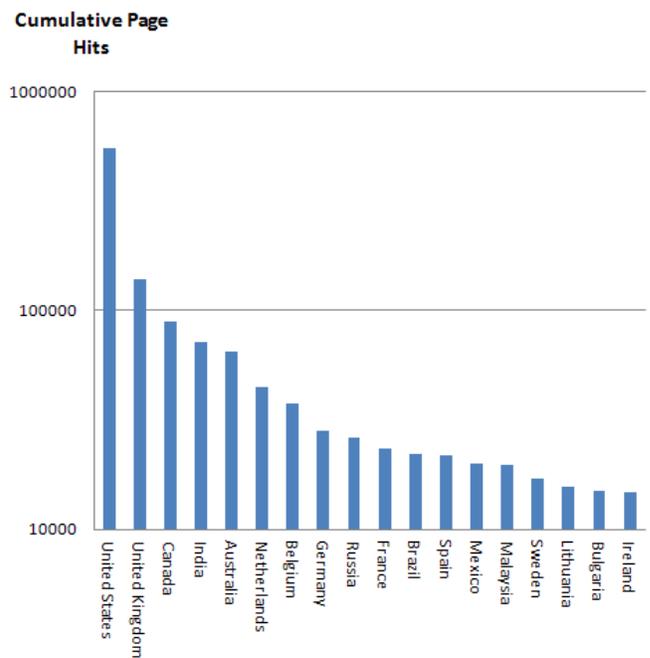


Figure 7. Total Views by Location

The fact that videos are popular doesn't necessarily mean they are effective. After all, the Internet is full of videos that get millions of hits, while having no instructional content at all. However, the videos on this YouTube channel have very little entertainment value and are not at all controversial. It is hard to conclude they are popular without being valued as teaching tools. A more direct bit of evidence is a steady string of positive comments from viewers. It is typical to get between 5 and 20 emails per day from struggling students commenting on how much the videos have helped in their studies.

Conclusions

The experience of creating a YouTube channel for engineering and engineering technology students has offered a number of valuable lessons. At this writing, the channel is attracting more than 3,000 hits per day, though that number varies during the school year. Hits have come from nearly every country on Earth.

Based on comments from viewers and direct conversations with students, the success of the channel is due in part to the short, focused nature of the videos and the fact that they show every step necessary to solve specific problems. The comment features in YouTube allow for several particularly useful types of interaction.

- Viewers very quickly report any errors or ambiguities in the videos.
- Viewers get to vote, thumbs up or thumbs down, on each video.
- Viewers can comment on the utility of each video.
- Viewers can ask for additional videos.
- Viewers can answer each other's questions.

Finally, the basic method described here is not difficult to reproduce. The hardware requirements are modest and there is very little editing required. With practice, a good video can be produced in two hours, start to finish.

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Biography

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UNDERGRADUATE APPLICATION-BASED RESEARCH: DESIGN AND TESTING OF A WIRELESS PHONE CHARGER

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Abstract

Currently, there exists an abundance of handheld electronic devices, especially smart phones that require frequent charging. Traditionally, these devices were charged by using wired power adapters (chargers). However, the use of wires poses limits in terms of user convenience and distance from electrical outlets. While wireless chargers exist, commercial widespread use of the technology for consumer electronics is relatively recent. Also, the application of the underlying science and engineering principles of power transfer wirelessly are not commonly explored in Electrical Engineering Technology (EET) programs. In this paper, the authors report their findings and present the results of application-based research on the prototyping and testing of a wireless charger. This research was conducted as an independent study course by one student, who was supervised by an Electrical Engineering Technology professor. The design procedure is explained, tests results are presented, lessons learned are discussed, and ways in which the project could be incorporated into the lab component of an Electrical Engineering Technology course are suggested. Lastly, the authors suggest ways in which their design and approach could be improved.

Introduction

Ever since Tesla demonstrated lighting phosphorescent lamps wirelessly in 1893, the scientific community has been aware of the principles of power transfer through magnetic induction [1]. However, in the past, the inherent inefficiency of this method and the typical amount of power required for operation of electrical devices inhibited the proliferation of wireless adapters. Nowadays, the advancements in integrated circuit (IC), communication, computing, and battery technologies have led to much smaller and more powerful communication and computing devices with highly efficient batteries. These devices consume much less power than comparable devices years ago. A Blackberry smart-phone only needs electric current on the order of milli-Amperes (mA) to operate properly. Thus, if it is possible to transfer a small amount of power wirelessly, even considering significant power loss, it would be sufficient to charge a Blackberry, iPhone, or a similar smart phone. Due to the quantity of

power required by these contemporary devices, the tradeoff of inefficiency in the transfer of power can be reasonably sacrificed for the convenience of charging wirelessly. However, the underlying science ultimately limits the amount of power that is transferred over varying distances.

Wireless electricity is an emerging technology and, thus, there exists much room for innovation. There are several consumer electronic devices that can be charged without using an electrical wire. Wireless power adapters are now commercially available for smart phones, iPods, and other similar low-powered devices. The underlying engineering concept for the wireless power adapter is similar to electric toothbrush chargers, in that they use the principle of magnetic induction to transfer power from the base to the brush handle (functioning device) [2]. However, the latest wireless chargers are more sophisticated and more powerful through the utilization of magnetic resonance that enhances power transmission speed and efficiency.

There are two fundamental types of wireless electricity transmissions. The first method uses magnetic induction technology and requires some kind of charging pad on which to place devices. These pads facilitate the charging of multiple devices such as smart phones, cameras, and iPods, simultaneously. The second method uses wireless antennae to transmit power through the air, requiring no charging pads. This method is quite promising but is not without its drawbacks; some researchers are concerned about the potential health hazard this poses through prolonged exposure to emitted electromagnetic waves. This current research project focused on the former method that utilizes a charging pad.

The objectives of this application-based research project were: (i) design and build a prototype of a wireless power adapter for smart phones, (ii) demonstrate its operation, and (iii) measure the amount of power transferred with varying distance of air or through a nonmetallic surface. The motivation for this project was the need to develop an avenue for application-based research in a crowded EET curriculum. The thrust of this project was to conduct an empirical investigation. Software simulation, while utilized in the design phase, was not a main driver in the overall design. It was hoped that the successful completion of this project would

allow both researcher (student) and research supervisor (professor) to gain valuable insights into the usefulness and role of application-based research in the EET program through the shared experiences.

Theory of Induction

Induction can be defined as the production of an electric current through a conductor placed in a varying magnetic field. Ampere's law states that "the magnetic field in a space around an electric current is proportional to the electric current which serves as a source" [3]. This basically means that when a current is moving through a conductor, a magnetic field proportional to the current is produced around the conductor. From this law of physics, it was derived that the amount of current that flows through a wire/inductor coil would have an effect on the distance that power could be transferred between two conductors separated by air. In addition, Faraday's law of induction states that "the magnitude of the electromotive force (emf), or voltage, induced in a circuit is proportional to the rate of change of the magnetic flux that cuts across the circuit"[4]. In other words, when a conductor is placed in an alternating magnetic field, a voltage is induced across that conductor.

A changing magnetic field can be achieved by reversing the polarity or direction the current flows through the conductor. This can be easily done by connecting the wire/conductor to an alternating current source such as a 120V AC power outlet. Therefore, theoretically, utilizing a direct current (dc) source would not result in any transference of power.

Design

The purpose of this application-based research project was to design, build, and test a circuit that could charge the battery of a smart-phone wirelessly. The wireless transfer of power is possible by using two inductively coupled coils that transfer power via the magnetic field of the coils, in accordance with the scientific principle of magnetic induction [5]. In this design, two separate circuits were utilized, one attached to the primary coil and the other connected to the secondary coil. The primary coil was connected to the driver circuitry, which was sourced by the power supply. The secondary coil received power from the primary coil's magnetic field and its circuitry transformed the signal into an appropriate form so that it could be used to charge the smart-phone device. In order to successfully transfer power through the air using magnetic induction, a certain signal needs to be applied to the primary coil. According to the

definition of induction, an AC signal needs to be applied to the primary coil and received by the secondary coil.

The base/pad of the device was plugged into the wall. However, the voltage of 120V RMS and a frequency of 60 Hz from the wall outlet were unsuitable for transferring the power required for our design. Thus, it was necessary to increase the frequency, which made it much more efficient in transferring power via magnetic induction. However, since smart phones operate at much less than 120V, it was also necessary to reduce the voltage. This was achieved by placing a transformer-based power supply between the AC outlet and the primary coil (see Figure 1).

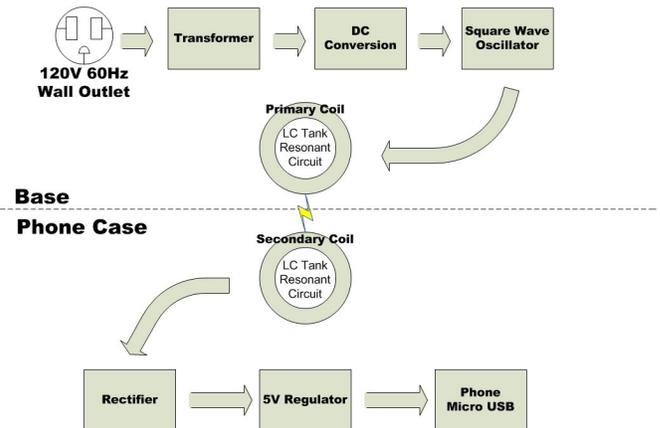


Figure 1. Block Diagram of a Wireless Power Adapter

Transformer and Power Supply

The operational amplifier, or op amp, is powered by a DC voltage source. Since the op amp had to be powered by a DC voltage source, the researchers decided to build a DC power supply that was able to plug into the AC wall outlet. A +15 to -15V split power supply that delivered a 30V peak-to-peak square wave signal at the output was designed and constructed. The 30V peak-to-peak signal was selected as a design specification because that voltage level was sufficient for this application. Also, this voltage level was not too high so as to interfere with the limits of the electronic devices that were being utilized [6].

The operation of the transformer was also based on the principle of magnetic inductance. It consists of a primary and secondary coil, which are wrapped around two sides of a square ferrite magnetic core. The voltage on the primary side creates a flux in the magnetic core and, thus, transfers electrical power to the secondary side. The voltage on the secondary side was determined by the ratio of the primary and secondary windings. This relationship is defined by Equation (1). A step-down transformer was used for this

project in order to convert the 120V RMS voltage and transform it to 36V RMS on the secondary side [7].

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \quad (1)$$

where,

V_S and V_P represent the voltage across the secondary and primary coils, respectively. N_S and N_P represent the number of turns on the secondary and primary coils, respectively.

The output signal of the secondary coil was rectified by the configuration of diodes, filtered (smoothing) by the capacitors, and then regulated by the LM 7815 IC regulators, as shown in Figure 2. The resulting signal was a positive and negative split DC supply. A 36V CT Transformer [7] was selected because a regulated 15V was desired. The center tap enabled 18V to be on both the positive and negative rail, splitting the 36V. The voltage on the regulators was 18V and not 15V in order to compensate for the voltage drops across other passive components, thus keeping the regulators' input above 15V [7]. The split DC signal from the power supply was fed into the oscillator circuit. [7]

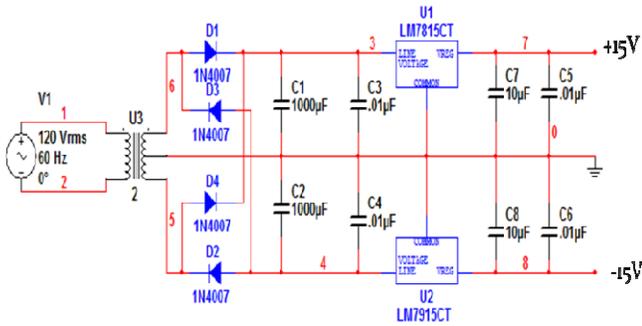


Figure 2. DC Power Supply

Oscillator

The output of the oscillator was an AC signal with a frequency much higher than 60Hz. The oscillator is the last stage that drives the primary coil, as shown in Figure 1. This AC signal in the primary coil produces an alternating magnetic field around it. Since the secondary coil lies in the magnetic field of the primary coil, a current is induced in the secondary coil. It was certain, based on the theory and laws of physics, that it had to be an AC signal, but it had to be determined whether this should be a square or a sine wave. To figure this out, the primary coil was connected to a function generator so that the emf induced on the secondary coil could be measured. By doing this, it was observed that the voltage induced on the secondary coil was consistently larger when a square wave was used in comparison to

using a sine wave. From this empirical investigation, it was decided that it would be more appropriate for power transfer. The theoretical and or mathematical explanation as to why this occurred was beyond the scope of this project. [8]

To generate the square wave, it was necessary to transform the main voltage signal from a wall outlet to a square wave of the desired frequency and voltage. One might consider generating a square wave with a 555 timer integrated circuit (IC). However, this IC does not have a high enough output voltage and the output signal is a pulse and not an AC waveform, as was desired. The 555 timer chip specifications do not accept a negative supply voltage in order to output the necessary AC signal [9]. Based upon previous research, it was decided that an op-amp-based square-wave oscillator would be used. This oscillator circuit is shown in Figure 3 [8]. Equation (2) expresses the relationship between the frequency and the values of the passive components in the oscillator circuit used, where R_1 , R_2 , and R_3 are resistors and C_1 is the capacitance of the capacitor.

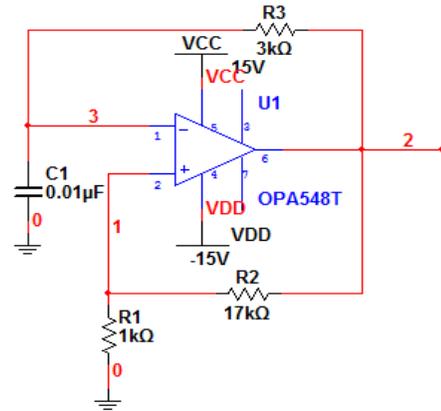


Figure 3. Square-Wave Oscillator

$$f = \frac{1}{2R_3C_1 \ln \left[\frac{1 + \left(\frac{R_1}{R_1 + R_2} \right)}{1 - \left(\frac{R_1}{R_1 + R_2} \right)} \right]} \quad (2)$$

The square-wave oscillator outputs an AC waveform with a frequency of 150 kHz [10]. The combination of its feedback loops and timing capacitor causes the circuit to act like a comparator. This results in the oscillation of the output signal between +15V and -15 V. The frequency of 150 KHz was selected in order to match the self-resonant frequency of practical inductor coils [11]. If the frequency is too high or too low, skin effect and the inductor's size affect the inductor's ability to transfer power without significant power loss. A frequency of 150 kHz facilitated the creation of

practical coil windings and the use of standard capacitor values in the construction of the resonant tank circuit, which is described later in this section.

Coils

The parallel tank circuit provided a high-impedance matching given that the load resistance of the inductor coils was very low. Since the desired design frequency was 150 kHz and a standard and reasonable capacitor value of 0.1 μF was selected, Equation 3 was used to calculate the required inductance of the coils [12].

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

where,

f represents the operating frequency, L represents the inductance of the coils, and C represents the value of the capacitance of the capacitor in the tank circuit [5], [12]. Using this formula, a value of 11.2 μH for the inductance of the coils was computed [13].

In addition, the relationship between the inductance and the dimensions of the coils can be expressed as follows by Equation (4).

$$L = \frac{R^2 N^2}{9R + 10l} \quad (4)$$

where,

L represents the inductance of the coil, R represents the radius of the coil, N represents the number of turns of the coil, and l represents the length of the coil. Equation (4) was used as a design constraint for the phone-charger application. A coil with a diameter of 2 inches was able to fit on the back of a typical size smart phone. Using 12 turns made it so that the coil was not too thick to fit in a phone case. (Bearing in mind that 22 AWG wires were used to wind the coils) The wire was wrapped around a 2-inch-diameter bottle, and then fixed into that shape by electrical tape to form a coil, as pictured in Figure 4 [5], [9], [13].

Figure 5 shows the schematic for the tank circuit. The operation of this is explained in more detail later in this section. Because of the slew rate, the time delay between the input and output of the op amp, the square wave signal was distorted, especially when the circuit was loaded. Hence, a Schmitt trigger was used to clean up the square wave. The Schmitt trigger outputs a square wave at its positive peak or negative peak voltage, depending on the values and configuration of the external components of the op amp. A Schmitt trigger is shown in Figure 6. Since the op amp of the Schmitt trigger is the last stage before the coil, this op amp

had to be a power op amp with high output current to drive the coil. For this project, the Texas Instruments' OPA548 op amp was selected [14], which accepts relatively higher voltage inputs and outputs, along with continuous 3A and 5A peak output currents. Although a smart phone only needs current on the order of mA to properly charge, the air losses of the induction coils need significantly more current to overcome the loss.



Figure 4. Taped Coil

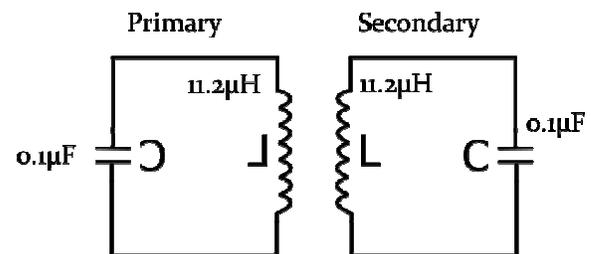


Figure 5. Parallel Resonant Coils

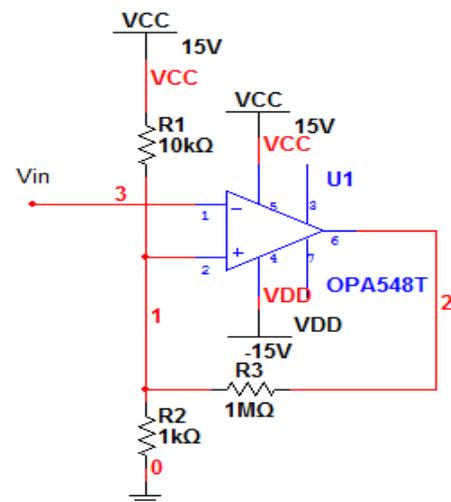


Figure 6. Schmitt Trigger

Also, in order to transfer power with minimal interference, a parallel resonant tank circuit, as shown in Figure 5, was used. This meant attaching capacitors in parallel with the primary and secondary coils separately. When a capacitor and an inductor are connected in parallel, they oscillate the signal between the two devices. The capacitor charges to capacity and then discharges into the inductor. The inductor generates a magnetic field that gradually increases in strength as the capacitor discharges into it. The magnetic field eventually collapses as the capacitor is discharged. After this, the capacitor starts charging again. The charging of the capacitor and the collapse of the magnetic field occurs repeatedly. This exchange causes the configuration of the two components, called a tank circuit, to produce an oscillating signal whose frequency is determined by the values of the components, and is expressed by Equation 3. If the primary and secondary coils have the same inductance and capacitor values, then they will both resonate at the same frequency [5]. Since they are interacting with each other by providing power to the second coil, the same resonant frequency of both tanks is used to block out unwanted interference and allow only the resonant frequency to be transferred. Figure 7 shows a schematic for the circuitry connected to the primary coil.

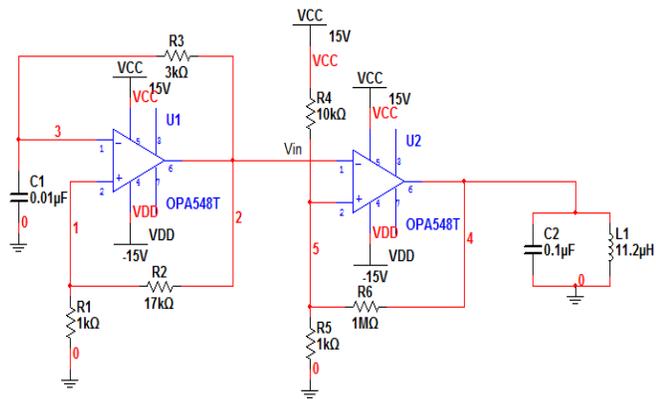


Figure 7. Primary Circuit Design

Receiving Circuit

The secondary side of the circuit was built into a phone case. Nowadays, a smart phone device uses a 5V USB plug to charge the battery. In order to achieve this voltage level, a bridge rectifier and a 5V regulator were used to convert the voltage signal in the secondary coil, which is AC, into a regulated 5V DC to power the phone. The receiving circuit takes the AC signal that was transferred into the secondary coil and converts it to a regulated DC using a bridge rectifier, capacitors, and regulator. In this research project the Blackberry Storm 9530 was used as the test tool that veri-

fied if the charging circuit was designed and constructed properly. The secondary side of the circuit was connected to this phone via its micro USB connector.

The bridge rectifier used four diodes to convert the AC waveform into a positive full "ripple" waveform. Filter capacitors were used in the same way as in the DC power supply described previously [2]. Also, for a more precise regulation, a 5V IC was utilized with its output connected to the micro USB male plug. The schematic diagram for this circuit is shown in Figure 8.

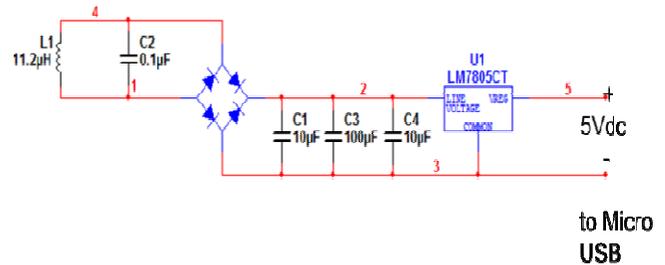


Figure 8. Secondary Circuit

Results and Discussion

Once the prototype was built, testing began in order to determine the charging capability of the wireless charger. It was quickly verified that there was current flowing in the micro USB and the phone began charging. The operational amplifiers and voltage regulators pulled about 500 mA, enough to heat the T0-220 transistor packages. Heat sinks were attached to the T0-220 packages to dissipate excess heat. From the testing, loading characteristics were noticed. Since the inductor was a wire wound in a coil shape, it had very low resistance. Due to the low resistance of the inductor, as the additional load was introduced in the primary circuit, a significant current flow was observed. The AC signal prevented the inductor from resulting in a short circuit. A large current through the inductor was necessary in order to generate a significant magnetic flux to transfer power.

Table 1 shows the amount of current flowing into the phone as the distance between the inductor coils was increased. This is consistent with initial expectations that power transfer diminishes as the distance between the inductor coils is increased. Typical wired micro USB phone chargers, on average, are rated at 500 mA output. A smart phone may draw more than 500 mA of current at times. The current output rating of the charger relates to the time in which the phone will charge. Since the circuit drew about 260 mA, as can be seen in Table 1, when the coils are clos-

est together, the phone would charge at a slower rate compared with a typical commercially available wired charger [15].

Table 1. Measured Average Current Draw

| Coil Distance (cm) | Phone Current Draw (mA) |
|--------------------|-------------------------|
| 0 | 260 |
| 0.5 | 150 |
| 1 | 100 |
| 1.5 | 50 |
| 2 | 10 |

After the square wave oscillator (OPA 551 op amp) received its DC supply, it outputted an AC square wave at a frequency based on its external capacitor-resistor values and configuration. The output waveform, as displayed on an oscilloscope, is shown in Figure 9. The waveform is oscillating at a frequency of 150 kHz [7] with a peak-to-peak voltage of about 30V. The waveform has more of a trapezoid shape than a square shape of the traditional square wave, due to the slew rate of the op amp. This is a practical characteristic of the op amp because of its inability to output the signal without a slight delay. However, no noticeable effect on the performance of the circuit that could be attributed to the slew rate of the op amp utilized was observed.

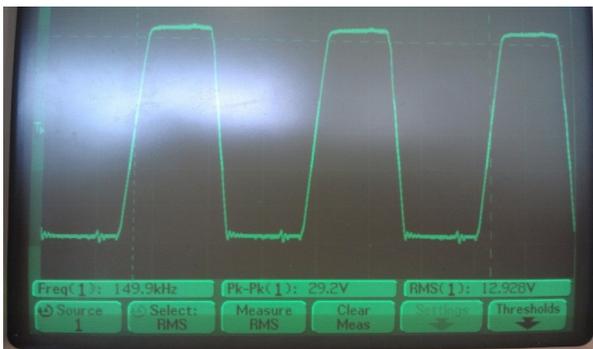


Figure 9. Square-Wave Generator Output

The output of the square wave generator was connected to the input of the Schmitt trigger. This, as can be seen in Figure 10, cleaned up the signal by reducing the small oscillations (ringing effect) on the peaks of the signal, while maintaining the same frequency and voltage.

After the transfer of power between the coils, the secondary coil was measured under load, as seen in Figure 11. The square-wave signal input had an effect on the output wave-

form of the received coil. The wave looks more like a sine wave because of the inductor's characteristic to resist the change in current, while building and collapsing the magnetic field. It resists by producing a back emf. The distorted sine wave was the result of this property. The frequency was relatively the same and the air gap losses were evident because a 16.4V peak-to-peak signal was received from the 30V supplied by the primary coil circuitry.

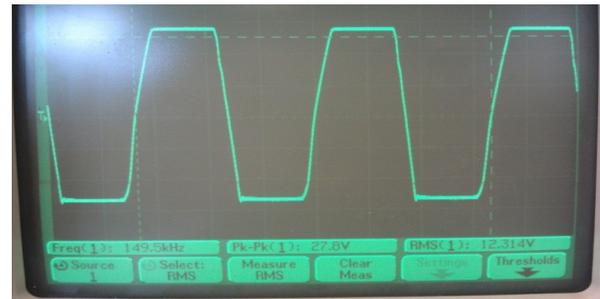


Figure 10. Schmitt Trigger Output

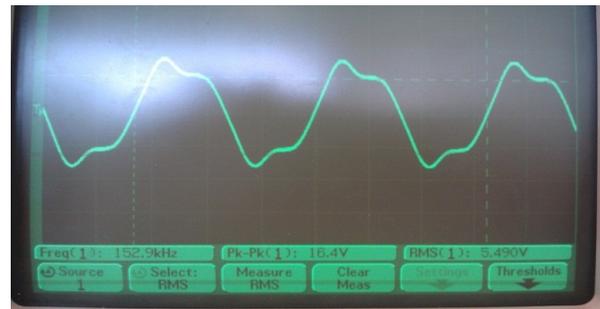


Figure 11. Signal at Secondary Coil

The received waveform was then rectified and regulated by the secondary coil circuitry. Figure 12 shows the output of the 5V regulator that was connected to the Blackberry phone. The oscilloscope shows no frequency and measures a peak-to-peak voltage of 160 mV. These measurements show that a low ripple “clean” DC signal was being outputted at 5V.

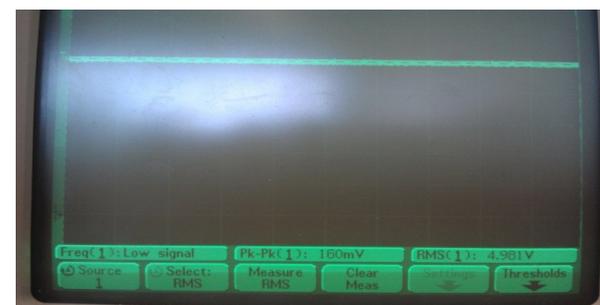


Figure 12. Secondary Circuit Regulated Output

Curriculum Integration

This project was completed in the students' final semester in Electrical Engineering Technology. The researchers believe, however, depending upon the sequence of electronics courses that it could have been completed in the junior year or the first semester of the senior year. It is recommended that this project be introduced as a series of mini-projects and be completed during regular lab times. Most EET introductory courses in electronics introduce students to the following devices and concepts: op amps, semi-conductor devices such as diodes and transistors, rectification, voltage regulators, power supplies, and pulse-generating circuits. In addition, the transformer and the principles of magnetic induction are usually introduced to students in introductory circuit courses and or physics, prior to doing electronics.

The laboratory work, depending on institution and instructor, will vary in approach. Some are very proscriptive and detailed and require the students to follow procedures in a mechanistic manner, while some simply give design specifications and allow the students a lot of flexibility in the design. Each approach has its advantages and weaknesses. The former tend to reinforce the theoretical concepts introduced in lectures and require comparatively less time. However, the student is not encouraged to be creative and these labs sometimes come across as being very boring. The latter allows students to be creative with predetermined design parameters. However, students lacking initiative may find these a bit too challenging. Also, more lab time has to be set aside for students. At SIUC, a combination of both approaches can be found in the junior and senior labs. Usually, the students begin their lab experience with very proscriptive and detailed labs and, as they acquire the requisite skills and knowledge, design labs are introduced with increasing complexity as the semester progresses. A similar approach is recommended in introducing this application-based research into the regular curriculum.

Conclusion

Today's engineers are always trying to improve technology in order to enhance the quality of life. The technology and theoretical foundations of power transfer through magnetic induction have been in existence for a long time. However, this method was not practical for most practical applications due to the inefficiency, power loss, and amount of power that would be required to operate electronic devices. Nowadays, with the advent of low-powered devices such as smart phones and tablet PCs, the application of magnetic induction has become much more practical. This technology allows consumers the flexibility and convenience of wire-

lessly charging their phones and other computing devices. This application-based research project included the research, design, construction, and testing of a wireless smart phone charger. The results of the tests demonstrated that the prototype performed well up to 260 mA at 5VDC. These values are comparable to commercial wired charges (power adapters) and satisfied the operating requirements of the smart phone.

Future Work

As with most electronic designs, there are different ways to achieve the same results and even improve on the original design. The design choices for this project were motivated by three factors: energy efficiency, physical dimension of coils, and cost. However, several improvements could be made as the design choices and constraints are modified. For this project, a sine wave signal instead of a square wave signal could be used to drive the coil. The sine wave will still transfer power as long as the waveform is AC. In order to drive the coil with a sine wave, the square-wave generator and the Schmitt trigger should be replaced by a sine wave oscillator [16]. Also, instead of using op amps to drive the coil, Bipolar Junction Transistors (BJTs) or Field Effect Transistors (FETs) can be used for better power handling capabilities. [17]

Push-pull transistor designs can create a very efficient sine wave oscillator that is able to produce high currents with less heat generation. MOSFET transistors are also good choices for the push-pull design. During the post analysis of the project, it was determined that the ZVS (zero-voltage switching) driver circuit may have been an appropriate improvement of the design. This circuit is a MOSFET oscillator that is able to oscillate a large amount of power with little loss. In the ZVS circuit, the MOSFETs switch when there is a potential difference of 0V across them. Since they switch at 0V, the power loss due to switching is very small, resulting in the production of very little heat by the MOSFETs [18].

In the near future, the researchers envision the development of furniture that has the power transfer via magnetic induction capability built-in. For example, a desk can have this device built-in and could power/charge a compatible cell phone or laptop just by setting it on the surface of the desk. This is the beginning of this kind of technology; the ultimate goal would be to have your device charge by just walking into a room. Your cell phone would charge in your pocket and your laptop would charge at any location in that room.

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SMART[®] TECHNOLOGY LEARNING TOOLS: ANALYSIS OF INDUSTRY LEADER PERCEPTIONS AND SATISFACTION

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Abstract

In this paper, the authors describe a recently conducted university sponsored study to foster relations with local executive industrial leaders of global companies. The executives and upper-level managers verbally expressed both their perceptions and/or satisfaction about using interactive tools (SMART) for routine project management activities such as: communication with customers, quality control, and technical education training. SMART is a brand of device generically referred to as an Interactive White Board (IWB). An IWB allows instructors or professionals to collaborate with an audience, draw, and interact with information on a universal and ubiquitous screen across distances. However, dynamic multi-sensory learning affects both decision-making and technological industrial innovation, especially concerning productivity. Using “SMART Boards” (as a representative example of an innovative technology) might indicate potential corporate progress. Possible novel activity addresses risk-aversion, traditional bureaucratic organizational pressures, and appeals to active rewards for risk-tolerant peers. Unawareness and, sometimes, resistance of leaders towards adopting new educational training evidences possible disconnects for company-wide innovative and entrepreneurial growth. Thus, there are multiple types of models through creative University-Industry (U-I) approaches, depending on the fit with specific organizational risk-taking. The impact of overall innovation in advanced industries might provide clarification as to how the misperception of technology, by executive leadership, transfers or equates to market success.

Introduction

A SMART[®] Interactive White Board (IWB) enables collaboration across industry learning platforms by providing flexibility, versatility, multimedia ability, interactivity, and save-drawing/file sharing. “An IWB is a presentation device that is connected to a computer” [1]. Global teamwork is morphing towards a rich multi-dimensional experience where “industry expects their companies to use some level of educational technology”. The pilot study specifically within leading advanced manufacturing industries con-

firmed both awareness for integrating information across sharing platforms and that communication technologies are likely necessary. Most SMART studies on perception are found at the K-12 level. Some studies discuss collegiate use of SMART technology, but there is nearly nothing in the canons of SMART industry metrics on either satisfaction or perception regarding IWB use. Indeed, “there is troubling evidence that a growing number of institutions are not keeping up in the battle to keep these systems functional and relevant due to budgetary shortfalls and sadly, SMART classrooms are ‘turning dumb’ due to neglect” [2]. Whether or not collaboration is a necessary strategy in transforming productivity and encouraging innovation is the centerpiece of further research.

Background

The technological age is a term that no longer describes the future; it is here and now and surrounds institutions or industries on a daily basis. Human nature is to either embrace change, or resist it. Organizations that embrace the change in technology will have a huge competitive advantage over those that do not. Technology allows organizations to save time by planning meetings, sharing files, communicating via web-conferences, and, overall, increases productivity [3]. The term technology is a very broad term; therefore, this research was narrowed down to focus specifically on SMART Board Technology (SBT), or what is referred to as an IWB. SBT includes the ability to “write” on the board, record all sessions, use video streaming, and deliver content via Internet or video programs, all within a large, interactive, touch-screen surface within a secure environment.

The research conducted on SBT thus far has mostly been limited to the academic environment [4-6]. Academic research shows a positive relationship between SBT and student learning, student satisfaction, and student outcomes [5]. Additionally, SBT transforms the classroom into “a stimulating, dynamic, and collaborative learning environment” [6]. Although simultaneously displaying multiple documents and multimedia presentations is appealing to students, research is lacking on how this technology translates into a global competitive advantage for organizations.

There is some literature suggesting that SBT does bring innovation, collaboration, and productivity to an organization [7].

In a globally competitive environment, organizations that do not embrace innovation will be left behind and face the reality of reduced market share. The key for any organization is to implement innovation into their long-term strategic plan. Organizations that fail to embrace innovation are on a path to failure. Companies such as IBM, Xerox, General Motors, Kodak, and AT&T are examples of large organizations that allowed other innovative companies to pass them by [8].

Globalization is critical to succeeding in the worldwide economy. As the world becomes flatter and progressively more interconnected, more and more organizations are asking questions about the importance of cross-cultural collaboration. SBT may be one answer to the globalization phenomenon, but organizations and individuals must be willing to embrace the technology in order to obtain the competitive advantage it brings. British Telecom (BT), for example, installed 17 SMART Board interactive whiteboards each in Belfast and Glasgow, and two in India; this had a massive impact on travel costs, improved training, and reduced the carbon footprints significantly. Organizations must adapt, grow, evolve, and prepare for the future challenges of globalization [9], yet many organizations seem to be resisting or avoiding change.

In addition to research on IWB themselves, human factors must be considered. The focus of this study was to determine how executives and upper-level managers perceive technology and their willingness to adopt new toolsets. Much research has been conducted on how individuals cope with adopting technology in the workplace. One critical factor is resistance to change as a result of “challenges to sense of self” [10]. A second critical factor is the investment in technology versus the Return on Investment (ROI). The question, is do executives and upper-level managers believe that investing in new technologies such as IWBs will result in increased innovation and productivity. Boothby et al. [11] concluded that productivity gains are aligned not only with technology adoption but also with training related to the effective use of technology.

The goal of this current research project was, first and foremost, to understand the perspective of executive leaders and upper-level managers on using SBT within their organizations. Without the willingness and awareness of top-managers, it is almost impossible to obtain approval to adopt new technology into their organizations. The first step is to understand where organizations are in order to help

them advance to where they need to be. Integrating information and communication technology (ICT) is forging new paradigm shifts in collaboration that is at the heart of pedagogy and the educational experience inside and outside of the classroom [12]. Such an iterative process begins the social, political, and economic concert for customers and companies to communicate across the street or across the globe using IWB interfacing.

Limitations of the Study

Of note, this paper resulted from a pilot study conducted with a seed grant from Purdue University. With regard to future research, the current study requires further clarification. The survey that was used encountered participant confusion where the response may have been different depending on question clarity. Secondly, only two companies participated and, in order for statistical validation, more entities should be polled. Finally, the participants were not of the same level of management, which likely yielded skewed data. Given that the work herein is only a pilot study, more effort and resources are required to carry out a full and effective research platform.

Methodology

The purpose of this study was to identify perception and satisfaction levels of industrial executive leaders and upper-level managers using new interactive technologies/equipment (such as IWBs) for daily business activities. The research methods employed a quantitative design based on the analysis of survey questions obtained from participants after short 20-minute presentations of IWB features.

Data collection took place during two phases. The first phase was conducted in March, 2013. Participants in this phase included two executive-level and four upper-level managers employed by Subaru of Indiana Automotive (SIA), Inc. They were invited to the local vendor area reseller (VAR) office for SMART, who sells/supports IWB technologies. The vendor conducted a 20-minute presentation about IWB features. Afterwards, participants responded to survey questions regarding satisfaction, perception, and probability of using SMART or IWB products for everyday activities.

The second phase was conducted in April, 2013, and was organized under the same scenario as the first phase. Eleven upper-level executive managers employed by the Wabash National Corporation (WNC) participated in a similar 20-minute vendor presentation about IWB features and responded to the same survey as the first group. The only dif-

ference between the two presentations was the location; the WNC presentation took place at an onsite conference facility instead of the VAR's office.

Participants

Both companies are prominent transportation manufacturers located in Indiana. SIA is a notable worldwide car manufacturing company. WNC is an internationally recognized trailer manufacturer. Both companies claim to be innovative and adaptable to new technologies. A total of 17 people participated in this study. According to the demographic questions, there was a strong male dominance in participant groups: 71% reported their male gender; 18% were females; and 12% of the participants ignored this question. The majority of the executive leaders in both groups might be recognized as a "young generation"; for example, 24% of participants reported their age in the 25-34 category. An additional 29% described their age in the 35-40 category. Another 24% reported their age in the 41-50 category; and only 12% reported their age as being 51 or older. Six percent of the participants skipped this question. Regarding the question about specific management levels (the number of people that participants supervise on a daily basis): 49 % reported that they manage 7-20 people; 18% manage 21-250 people; and 12% of the participants supervise up to 5000 employees. The educational background of participants was shared between a BS (47%) and MS (35%) degrees. Only 6% reported attending a technical school; the other 12% did not report their education.

Survey Instrument

The survey instrument used for this study was designed by the research team and contained two parts. The first part consisted of seven questions related to the users' perception of the IWB. The second set was comprised of six demographic questions. It should be noted that some participants were concerned about misinterpreting the survey question; thus, for future research, this instrument should be modified to avoid vagueness in the questions. The survey employed a 7-point Likert scale:

- Scale 1- Very unsatisfied (do not use it);
- Scale 2- Usually dissatisfied (but learn it because forced minimal use);
- Scale 3- Dissatisfied but manageable (force myself to learn but try to remain positive);
- Scale 4- Neutral (use it only when required);
- Scale 5- Satisfied but hesitant (do not use as often as possible);
- Scale 6- Satisfied in most cases (believe that it is effective for the organization);

Scale 7- Very satisfied (always try to apply in different settings).

Results and Discussions

The first survey question asked: When your company conducts business meetings or educational events, what technologies are used? From the provided list, participants had to choose from toolsets such as: computer, projector, SMART Boards, Skype, SharePoint, WebEx, and Citrix GoTo Meeting.

Figure 1 gives an illustration of the options chosen by the participants. Of the participants, 94% selected computers as the most regular way to conduct meetings; 88% chose projectors. SharePoint, WebEx, and Citrix GoTo Meeting were each selected by 47% of all participants; 18% of the participants used Skype, while only 12% selected IWB's (also called SBT). Thus, despite the fact that IWB technologies have existed for the last decade and are widely accessible on the market, they are still considered a sophisticated and less frequently used product. It is noteworthy that the technologies used by both sets of managers differed, whereas one group was familiar with the IWB activity and the other was not familiar with the IWB technology whatsoever. To facilitate the effective use of IWBs, training/support was provided to both the experienced and inexperienced users from the Purdue Research Foundation lab.

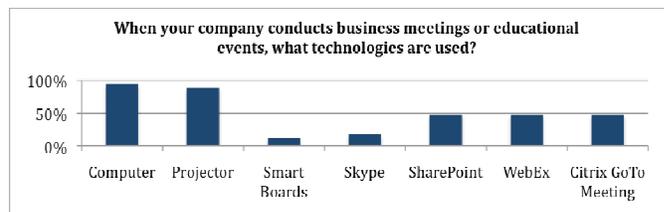


Figure 1. Survey Question 1

The second question asked participants how comfortable they feel using the previously mentioned technologies/tools for company projects. This question was designed to measure overall comfort levels with the technologies that are currently used in their work setting. Further research might narrow down reaction(s) to specific technologies. Figure 2 gives a graphical interpretation of the selected options. Of the respondents, 71% claimed to be satisfied in most cases with the use of either computers or up the scale to IWBs. In general, they (the participants) believed that using these technologies impacts meeting effectiveness. Six percent of the participants were very unsatisfied; another 6% of the respondents reported being "usually dissatisfied but had to make it work." The participants also claimed to use interactive equipment rarely. Another 6% of the respondents were

neutral about this question; they reportedly use technologies only when required. Finally, the remaining 6% of the participants proclaimed to be satisfied but hesitant. These participants do not use technology as often as possible.

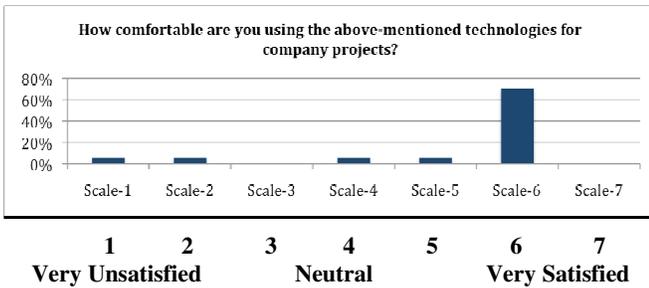


Figure 2. Survey Question 2

The third question asked: How easy is it for you to adapt or adopt new technologies within your company. Figure 3 shows selected options. Some 29% of the participants claimed that they were satisfied in most cases; they believed that using technology impacts overall effectiveness within their respective organizations. Another 29% claimed that they were satisfied but hesitant. These respondents tried new technologies as often as possible. There were 12% of the participants who were very satisfied with employing interactive tools. They reported that they always applied new technologies in different settings. Another 12% were usually dissatisfied but “had to make it work”; they attempted to use technology as minimally as possible. Six percent of the participants were dissatisfied but forced themselves to learn and remain positive. Finally, another 6% percent of the respondents were “neutral” about using all of the aforementioned technologies.

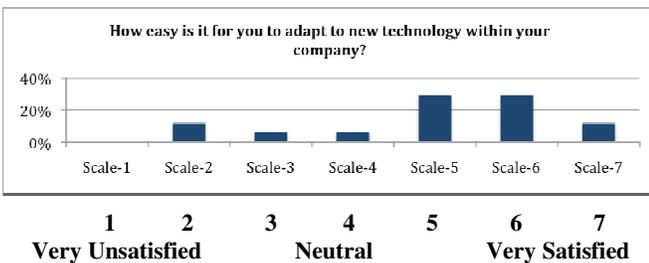


Figure 3. Survey Question 3

Question 4 attempted to understand the users’ perception/satisfaction in using SMART Board technology (IWB) after the 20-minute workshop. Figure 4 displays the selected options. A majority of the respondents, 47%, reported their satisfaction and believed that employing IWB’s will positively impact business effectiveness. Also, 29% reported being “satisfied but hesitant to use it.” They stated that they would not proactively use the IWB as often as possible.

Another 6% of the participants were very satisfied and claimed to apply it in different settings. Finally, 6% of the participants were dissatisfied, but managed their feelings and attempted to remain positive. Also, 6% of the respondents did not answer this question. Both presentations allowed the participants to witness and access the IWB capabilities live and in real-time. The presentations were hands-on alongside a demonstration of various capabilities to include shading, converting ink layers to text, and the ability to capture data (image and text) from the Internet in order to incorporate them into an embedded IWB presentation with the ability to even record the steps of designing the presentation [13]. The focus of the presentation was to investigate how IWB Technology enhances the level of communication through interactivity, while facilitating effective and productive meetings.

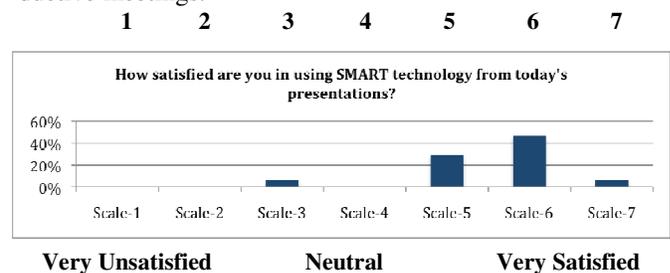


Figure 4. Survey Question 4

Question 5 asked participants to rate how IWB (SMART) technology can improve company and team dynamics. According to Figure 5, 53% of the participants claimed that SMART technology satisfied them in most cases. They believed that this technology could improve company and team performance; they also believed that it would be effective for overall organizational use. Another 24% rated SMART as (Scale-5) saying “IWBs would improve a company (or team) dynamic”, but they were still hesitant to use it on an everyday basis. Twelve percent of the respondents reported being “very satisfied” in rating SMART Boards as a tool. Finally, the last 6% of the participants thought that SMART Board tools would not impact the company performance or dynamics.

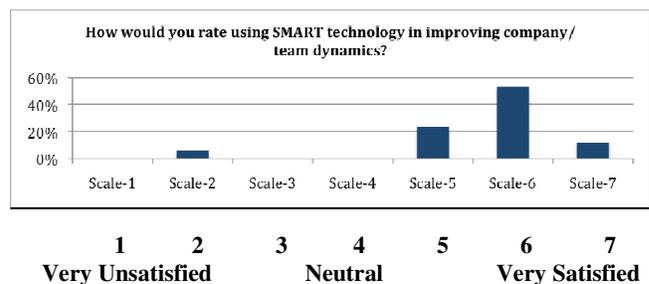


Figure 5. Survey Question 5

Questions 6.1 to 6.3 asked about different factors that would prevent the participants from using IWB technology from three different perspectives:

1. Financial—Am I ready to pay money for this equipment?
2. Motivational—Do I see the importance of this tool/technology? Is it necessary for the organization?
3. Psychological—Am I internally ready to force myself to learn about this tool and to employ it daily?

Financial Factor: According to Figure 6, 24% of the participants (Scale-7) were ready to purchase the IWB board. They understood the impact and value of this tool for business effectiveness and performance. Another 24% of the participants (Scale-5) expressed their satisfaction with SMART Boards, but felt hesitant to purchase it since they would not use it too often. Another 18% of the respondents (Scale-4) reported to be “neutral” about financial issues for IWBs. These participants might be indifferent because, in most cases, all expenses are carried from business accounts and personal cost is not involved. Twelve percent of the participants (Scale-6) reported their satisfaction “in most cases” and being ready to purchase it with recognition of the impact of SMART Boards on company effectiveness. The remaining 6% were dissatisfied and not ready to purchase SBT or an IWB.

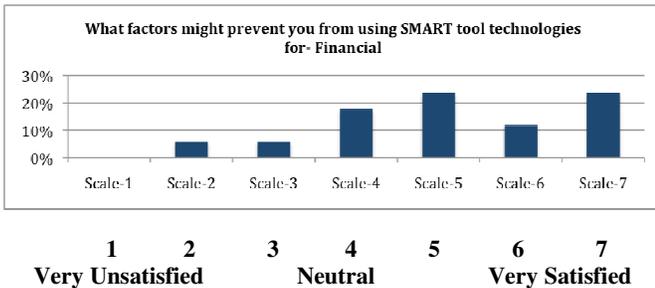


Figure 6. Survey Question 6.1

Motivational and Psychological Factors: Figures 7 and 8 present total options selected for Motivational Psychological factors, respectively.

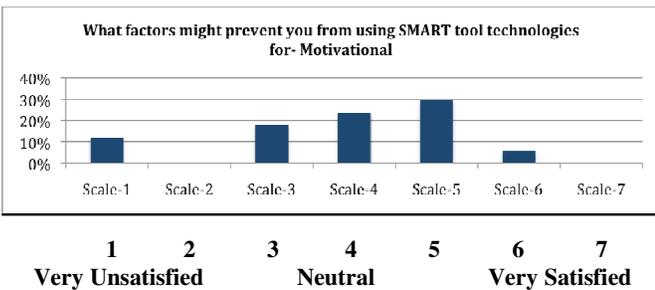


Figure 7. Motivational Factor

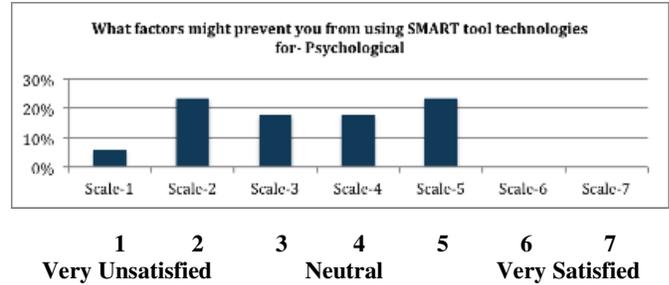


Figure 8. Psychological Factor

From a scholarly perspective, motivation is usually considered within psychology; therefore, these two factors (motivational and psychological) are analyzed together. Referring to Figures 7 and 8, only 6% of the respondents (Figure 7, Scale-6) reported high motivation and expressed their understanding and importance of IWB technologies for their company’s success. Not surprisingly, nobody reported a strong internal readiness, either to force technology adoption or to learn about new technology in order to employ it in everyday business life (Figure 8, Scales 6-7). Almost 30% of the respondents stated sufficient motivation—participants understood the value of the product—but were hesitant on decisive action (the peak, Figure 7, Scale-5).

Two interesting peaks were observed in Figure 8. About 24% of the participants reported sufficient readiness to force them to learn and use IWBs for their company diurnally; on the other hand, 24% of the respondents expressed a strong dissatisfaction, stating that they “have to make it work”, forcing them to be adaptive with new and up-coming technological tools.

After a 20-minute presentation of IWB features, participants answered the last survey question (Question-7) reporting their opinions on whether using the SMART Board during the presentation changed their perspective about IWB—and the possibility of increased productivity and efficiency. Figure 9 gives a graphical interpretation of the total options selected. Of the participants, 35% claimed their satisfaction with the quality of the presentation, using SMART; 29% expressed very strong satisfaction, suggesting that they would like to apply it immediately. Another 24% of respondents reported some hesitation towards IWBs but still remained positive and open to learning more. After the presenter’s presentation, each group was able to play with the IWB features. The purpose of this question was to measure how training and support would contribute to the receptiveness/willingness of the participants to use the IWB in their organizations.

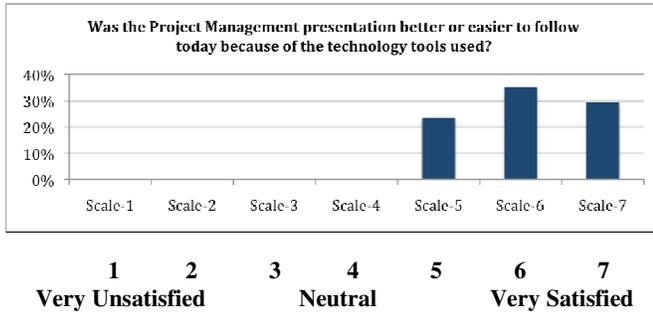


Figure 9. Survey Question 7

Conclusion

In summarizing the results of this study, a few significant things should be noted:

1. Although Interactive White Boards (IWBs) have been widely distributed on the global market during the last decade, they still remain an unknown tool (the market penetrations specifically of SMART Tech shows less adoption, currently and statistically, within industry as opposed to the penetration of the K-12 education markets) even for top executive management and upper-level managers in high-tech manufacturing industries in the United States. SMART technologies are not broadly used as designed, and many IWB features remain unclaimed. Another perspective regarding the use of IWB's is that a literature review clearly shows that the majority of research into Interactive White Boards reflects their use in education, particularly K-12. As a reminder, SMART was simply used as the device or representative model of IWB Technology potential.
2. After short, informative presentations, the overall majority of the participants had a very positive attitude/perception/satisfaction regarding IWB concepts for company needs, even though a small number of participants did not have the motivation for immediate action. Although participants indicated that the adaptation of new technology might be challenging (early in survey), the majority of the responses showed that satisfaction increased after the presentation, demonstrating the capabilities of IWB technology.
3. Financial cost was not the most determinative factor for the decision of "to-buy" or "not-to-buy" the tool. The most influential factor in the decision of purchasing and using this technology was the "internal psychological readiness" of managers to be personally

involved with the new SMART or IWB technology tools.

4. Further research is needed with respect to industry perception/satisfaction around SMART Board technology and the use of IWB methodologies.

Acknowledgements

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INFUSING FACULTY RESEARCH AND INDUSTRY REQUIREMENTS INTO MULTIDISCIPLINARY ENGINEERING TECHNOLOGY CAPSTONE PROJECTS

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Abstract

Capstone or senior design projects are widely acknowledged as important components in Engineering and Engineering Technology undergraduate education. The benefits of capstone design projects have been extensively presented in the literature. However, a high percentage of capstone projects deliverables do not result in an operable system that follows industry standards and guidelines, or cover a complete product or system development lifecycle with focus on sponsor and user needs. In this paper, the authors present a multidisciplinary senior design strategy integrating funded faculty research and industry requirements. Students participating in this type of senior design are directly involved with all aspects of a complete system development cycle, focusing on user needs and requirements. All aspects of the project present higher quality and a larger scale than typical senior design projects and, in this way, better resemble industry projects. Moreover, the deliverables of these projects result in an operable system meeting user needs and industry-type specifications. The first case study presented here is the design, construction, and testing of a research-quality electric machine test bed, which has the purpose of furthering research and education in the area of power electronics and motor drives. The second case study consists of the design, construction, and testing of a small, photogrammetric small unmanned aerial vehicle (UAV) to be used for photogrammetric research and education.

Introduction

Senior capstone projects are challenging and important components in Engineering and Engineering Technology undergraduate education and usually teach students valuable skills in design, prototype construction, testing, teamwork, and project management related skills [1-5]. However, a high percentage of capstone project deliverables do not result in an operable system that follows industry standards and guidelines, or cover a complete product or system development lifecycle with a focus on sponsor and user needs [4]. A complete engineering project lifecycle includes planning and analysis, building and testing, implementation and maintenance phases, among others. Usually, capstone engineering and technology projects are product-oriented, focus-

ing only on the build and test phases of development [4]. This current approach serves as an additional element in the gap between what engineering disciplines teach and what skill sets employers expect of new engineering graduates. As pointed out by Selter [6], employers have indicated that new engineering graduates have technical competences but several lack the professional skills necessary to manage a real engineering project lifecycle, work with others collaboratively, and write and present proposals, among others. Based on a comprehensive national study, Howe and Wilbarger [2], [3] listed the 22 primary topics covered in engineering and technology capstone projects. The topics ranged from written/oral communication to CAD design and layout, but did not include any topic related to user needs or user testing. As a consequence, the focus was on the product end of the system development lifecycle, neglecting the user-centered analysis, design, test, and implementation phases of the development lifecycle [4].

In this paper, the authors discuss two multidisciplinary senior design projects integrating funded faculty research and industry requirements. The projects were the result of collaboration among faculty, undergraduate, and graduate students of the Electrical Engineering Technology (EET) and Surveying Engineering (SE) programs in the School of Technology and the Electrical and Computer Engineering (ECE) department in the College of Engineering at Michigan Technological University. The projects gave students the opportunity to be directly involved with all of the aspects of a complete system development cycle, focusing on user needs and requirements. In the engineering and engineering technology programs at Michigan Technological University, students were required to complete a two-semester senior design project, which was typically industry-sponsored, allowing students to work on real-world projects. More recently, however, some of the capstone projects were sponsored by faculty members instead of industrial partners. This initiative served to support some funded faculty research projects, and allowed undergraduate students participating in the project to interact with graduate students, faculty members of the college of engineering and school of technology, and customers. Design, construction, system integration, software, and testing all involved other researchers instead of just the capstone team which, in turn, created new project management challenges such as team

work, communication, documentation, and scheduling, among others; thus resembling a larger scale project in industry. The assessment methodologies for the senior design courses used indirect and direct measurements to assess the applicable ABET a-k criteria [7]. The assessment results indicated improvements in the student comprehension of key concepts and increased students' confidence to start their career in the industry.

Case Study I

Research and education into various methods of improving energy efficiency for electrical devices has become increasingly important to meet future energy needs. Because of this need, an electrical machine test bed was designed and built for the purpose of furthering research and education in the area of power electronics and motor drives. Both the engineering education and research capabilities aspects of this test bed have an important role in providing engineers with skills to quickly contribute to the power and energy-related industry. The project followed practical industrial project standards and all aspects of the project presented higher quality and a larger scale than typical senior design projects; in this way, they better resembled projects in industry.

Dynamometer systems are used extensively in testing and verification procedures in various applications relating to automotive, industrial, and manufacturing fields. The advantages of using a dynamometer are to simulate a wide range of loads that a system may experience, precise controllability, and unit testing prior to the unit under test reaching the customer. Electrical machine drive systems are used in varying degrees of dynamometer systems for both research and design, and for product validation. In order to investigate some of the latest technology and control techniques for electric machine drives applications, an electrical machine test bed was designed and built for the purposes of both research into these topics and to compliment undergraduate laboratory courses in power electronics and motor drives. Additional motivation for having a dynamometer test bed came from the increasing penetration of electric propulsion into modern automobiles [8] and Michigan Technological University growth in hybrid vehicle education and research [9], [10]. Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV) both use electric machines for either full or partial traction of the vehicle. A dynamometer test bed was developed for the purpose of providing research into various electric-propulsion drive systems, including the flexibility to accommodate various types of machines. Such a test bed is a great asset to have in our power electronics research lab. In addition to the EV or HEV applications, a dynamometer test bed can also be used

to model a load in a small AC MicroGrid. This load could mimic the load cycle of hydraulic pump systems or a heating, ventilation, and air condition (HVAC) system of a small building.

This project allowed students to participate in the research of possible solutions and the selection of the one that would best meet sponsor criteria and user needs, then design, construct, and present a finished product. In addition to the application of knowledge learned in previous courses, students developed technical and soft skills such as: how to research and comply with current Occupational Safety and Health Administration (OSHA) standards for test beds, learn how to use AutoCAD for test bed layout and electrical schematics, practice industrial-type circuit construction, components select and acquire, learn and use industrial communication protocols, manage a project team, and deal with time management. The students also further developed critical thinking and accountability.

Design Requirements

The faculty sponsoring this project had specific industry-type requirements that had to be followed by the team, including:

1. A test cell safety system following OSHA standards—also, devices must have adequate guarding to protect users from injury; use of cable tray to protect cables; safety relays;
2. Efficient use of space—cell must be as compact as possible to fit in the available room;
3. Wired communication with laptop for configuration;
4. Variable frequency drive (VFD) must communicate via Modbus RTU receiving its commands from the test cell PC;
5. VFD step-up transformer, since VFD operates at higher input and output voltages than the test cell infrastructure voltage supply;
6. High accuracy torque/speed monitoring;
7. Test cell infrastructure controls must be PLC-based and independent of the VFD and inverter controls;
8. PC-based controls; user interface controller station with National Instruments LabVIEW GUI, dSPACE embedded controllers, Allen-Bradley Micrologix communication adaptor, and operator pushbuttons station;
9. Inverter with opto-isolated (fiber-optic) gate drive and fault signal output for electrical isolation and noise immunity;
10. Signal isolation to isolate any control signal input signal to the one that will be connected to the dSPACE embedded controller;
11. Electro-magnetic interference (EMI) isolation;

12. Easy operation; and,
13. User manual.

Test Cell Design and Construction

The electric machine test bed is a collection of various commercially available and custom-made components. It was designed to enable a wide variety of electric machine configurations and applications, in order to provide a platform for testing of numerous projects. The current configuration of the test bed featured two identical 20 HP ABB induction machines in a back-to-back testing configuration. A one-line schematic is shown in Figure 1 for the current system configuration. The dynamometer is controlled via an ABB (full 4-quadrant) variable frequency drive. The prime mover machine is driven from a custom IGBT inverter controlled via a dSPACE embedded controller. Both shaft torque and speed were measured via a compact digital torque meter. The power wiring of the test bed was controlled by a Motor Controller and Safety System Enclosure (MCSSE). The MCSSE included a standalone programmable logic controller (PLC) system controlling the power flow throughout the system. The test bed machine mounting tables, shown in Figure 2, were built in modular fashion to accommodate various electrical machine types and sizes.

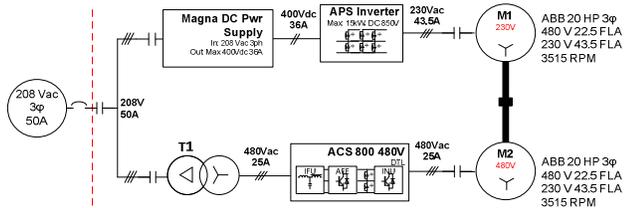


Figure 1. One-Line Test Bed Circuit



Figure 2. Test Cell – Start of the Project

The capstone projects in the Engineering and Engineering Technology Program at Michigan Technological University are comprised of two academic semesters. However, this particular project, since it also involved a graduate student, was completed in three phases: Phase I, during the fall semester of 2011; Phase II, during the spring of 2012; and Phase III, during the summer of 2012. In Table 1, the project's major tasks are highlighted in each phase. The graduate student participated on the team both as a technical advisor and as a project engineer. With this dual role, he contributed both to the completion of the EET senior design project and a successful commissioning of the test cell system. The fact that not all students were involved in the last phase of the project did not impose any overall problems for the students' experiences. Phases I and II consisted of the construction, system integration, and documentation of the test cell. Phase III was for additional parameter estimation and performance characterization. All the students participated in Phases I and II.

Table 1. Project Major Tasks

| Phase | Task |
|-------|---|
| I: | <ul style="list-style-type: none"> Cell Architecture Design Test cell Safety Research MCSSE Design MCSSE Parts Selection and Procurement MCSSE Construction Isolation Transformer Cabling and Connectors Embedded Controller/PC Station |
| II: | <ul style="list-style-type: none"> Initial Micrologix Program Expanded Micrologix Program w/ added features Test cell Power/Control Wiring ABB VFD Drive Configuration ABB VFD LabVIEW Program Motor Coupling/Torque Sensor Specifications Test cell User Manual |
| III: | <ul style="list-style-type: none"> Signal Isolation and Interface Board Signal Gain Tuning Electric Machine Parameter Estimation System Performance Characterization |

At the start of the project at the beginning of fall semester in September of 2011, some previous work was already done to acquire donations for the electrical machines and VFD, design and construct the test cell electrical machine table, attach the mounting hardware to the wall, and purchase various components for use in the test cell. The various components were comprised of a DC power supply, several inverters, and an electrical power meter with accessories.

During Phase I of the project, the team researched and designed an architectural approach, and ordered and constructed the Motor Controller and Safety System Enclosure (MCSSE). The first task completed was the design of the test power architecture shown in Figure 1. The test cell at the start of the project is shown in Figure 2, and the infrastructure enclosure MCSSE and subpanel are shown in Figure 3. The completion of these tasks included knowledge of the operation of the individual components and specific placement of the contactors to control electrical energy flow. The team researched and selected the components to be used in the MCSSE, which included an Allen-Bradley Micrologix controller, contactors, fuses/fuse holders, safety relay, terminal blocks, enclosure fan, DIN rail mounts, DC power supply, and wire way. The team was also responsible for the enclosure layout scheme and placement of the components on the back panel. The wiring schematic used to construct the MCSSE and test cell cabling was developed and guided the team with good practices in assembling the sub-plate and enclosure. Along with the enclosure and sub-panel, the team ordered the materials necessary for the complete test cell power cable routing. Several other components were also researched and ordered, including the isolation transformer, operation station computer, dSPACE embedded controller, PLC, safety relays, and high-voltage shielded power cables and connectors.



Figure 3. Test Cell Infrastructure: Subpanel

During Phase II of the project (spring, 2012), the team continued to research and order several components needed to complete the test cell. This included the flexible motor coupling, torque sensor, motor coupling guard, embedded controller, and control signal isolation modules. The conduit used for the ESPB enclosures/operations was bent, and the wiring of the high-voltage and communication cables was completed. The team also installed the analog control signal wiring between the work bench and controller station. Also during Phase II, the team programmed the initial Micrologix program that allowed running the test cell system. The graduate student worked very closely with the EET team member responsible for the VFD communication LabVIEW pro-

gram. They specifically set up the drive with the appropriate parameters to allow communication between controller station and VFD. The team also completed the power and signal routing, as well as the safety items necessary for operation of the dynamometer. Table 2 summarizes the main objectives and deliverable of the EET students.

Table 2. Team Objectives and Deliverables

| Phase I – Fall 2011 | Phase II – Spring 2012 |
|--|--|
| Project proposal | Incorporate PLC control of start/shut down procedure |
| OSHA Report | Fault detection |
| Components: Researched, selected, ordered | Sensor Integration |
| AutoCAD | Communication (ModBus) integration |
| Functional System | User documentation |
| Report/Presentation | Final Report/Presentation |

During the summer semester of 2012, Phase III of the project, the final items were completed for the fully functional system. These final items included control signal gain tuning, electrical machine parameter estimation, baseline system data collection, and test cell performance testing. The completed test cell system is shown in Figures 4 and 5. The test bed was primarily comprised of off-the-shelf commercial products. The components were integrated to form a functional electric machine dynamometer test bed. The one-line system was classified into two distinct portions: prime mover and dynamometer. In Figure 5, the top branch of the circuit, the prime mover, consisted of the DC power supply, A, and the DC-AC inverter, B. The lower branch of the one-line diagram was classified as the dynamometer and consisted of the isolation transformer, E, the variable frequency drive, F, and the second induction machine, Motor 2.



Figure 4. MSSCE Panel Layout

The current test bed configuration included two 20 HP ABB induction machines in a back-to-back testing configuration. The dynamometer was controlled by a four-quadrant ABB Variable Frequency Drive (VFD). In addition, a DC power supply and a couple of voltage source inverters (VSI) were available for use in this project. All of these components served as the essential components in the test cell system; however, system integration including some form of safety system was needed to safely control the behavior of the test cell. The test cell architecture was designed for two machines using a back-to-back testing configuration. A one-line schematic is shown in Figure 1. The two identical induction machines were mechanically coupled together via flexible motor couplings and torque sensors. There was only one source of electrical energy for the motors, a 208 Vac, 50 Amp, 3-phase receptacle, which was supplied from a power panel in the test bed room. This source would supply two loads: the magna DC power supply/inverter, and the ABB frequency drive. The Magma DC power supply powered the APS inverter which, in turn, supplied power to the Prime Mover electrical machine, M1. Because the frequency drive operated at a different voltage than the main power source, a transformer was needed. The frequency drive would then supply the Absorber electrical machine, M2. The high-level control scheme of the test cell safety system put the system in one of five states: Ready, Enabled, Powered, ON, and Fault. These states dictated what, if any, combination of contactors and indicating lights would be on.

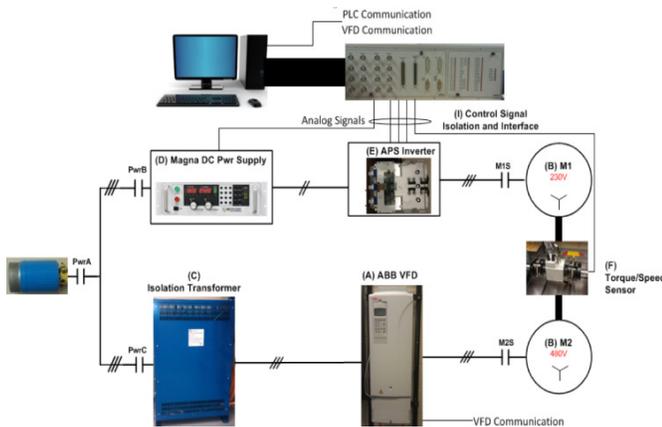


Figure 5. Test cell System and Component Integration Overview

Case Study II

The second case study consisted of the design, construction, and test of a small, photogrammetric unmanned aerial vehicle (PSUAV) to be used for photogrammetric research, road surveillance, and education. The UAV should be easy to use, safe to operate, and provide a stable flight so that

new students and researchers would not have a steep learning curve in operating the device. The UAV was also intended to be used as additional learning material for several classes. Similar to the first case study, this project was also completed in three phases: Phase I, during the spring semester of 2013; Phase II, during the summer of 2013; and, Phase III during the fall of 2013. In Table 3, the major tasks for each phase are highlighted. The project team was quite unique as it combined two domestic undergraduate students, three international undergraduate students (from Saudi Arabia and Brazil), and one international graduate student (from Greece). The students were also from different disciplines: Electrical Engineering Technology, Electrical and Computer Engineering, Mechanical Engineering, and Surveying Engineering.

Table 3. Major Tasks of the UAV Project

| Phase | Task |
|-------|--|
| I: | <ul style="list-style-type: none"> UAV parts design using Solidworks Individual parts combined into Solidworks assemblies Operating parameters calculation Parts Selection and Procurement Design simulated using Solidworks Flow simulation Analysis of materials for strength and weight for fuselage |
| II: | <ul style="list-style-type: none"> Vibrations analysis 3D printer Complete verification of Solidworks models camera mount using 3D printer Final assembly of parts Construction of UAV fuselage parts and using 3D printer camera mount using 3D printer Parachute protection design |
| C | <ul style="list-style-type: none"> Camera control |
| III: | <ul style="list-style-type: none"> Electronics analysis and components installation installation Kestrel AutoPilot implementation Sensors installation UAV testing |

A small, photogrammetric unmanned aerial vehicle is an unmanned aircraft designed for photogrammetry. Photogrammetry is the process of using a photo and known parameters to extract geometric properties. Specifically for this case, the PSUAV was used for surveying land. The PSUAV concept design is shown in Figure 6. This concept was tested in a previous study and proved to provide a stable flight [11].

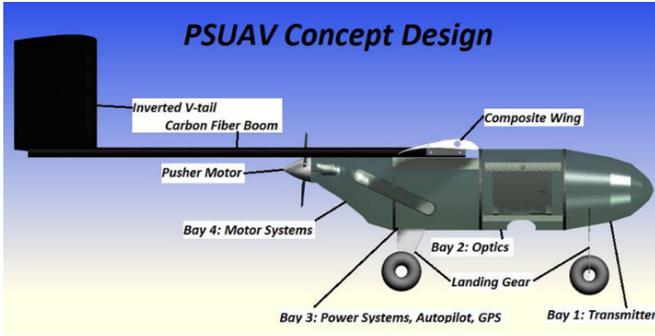


Figure 6. PSUAV Design Concept [11]

Design Requirements and Operating Parameters

Similar to case study I, the faculty sponsoring this project gave specific requirements to be followed by the team, including:

1. An operating altitude of 100-1000 meters, easily adaptable to future FAA regulation;
2. The use of a Kestrel autopilot system and Procerus virtual cockpit ground control station;
3. The use of a Cannon EOS Rebel Xsi digital camera;
4. A lightweight fuselage that would be strong and have low vibrations;
5. A camera-mount design with two rotational axes that takes into account the fact photos be taken parallel to the ground in order to ensure photogrammetry accuracy;
6. A parachute recovery system;
7. A design based on Solidworks 2013;
8. An aerodynamics analysis using Flow Simulation in SolidWorks;
9. A vibrations analysis using Matlab; and,
10. Appropriate stress, pressure, velocity, altitude, temperature, and air density analyses.

The design of the wings was based on the S1223 airfoil shown in Figure 7, which provided high efficiency at low airspeeds. The control surfaces used to operate the aircraft were ailerons. The UAV in this project made use of a V-tail, which was a simple design that allowed for propeller clearance. Through mathematical modeling and analysis, the team concluded that a 26" V-tail was ideal, but a 36" was used for the purpose of stability with a wingspan of 72". The fuselage was calculated to be 30" long. The PSUAV was driven by a Rimfire GPM4700 electric motor. The fuselage was designed using Solidworks 2013 and is shown in Figure 8. After much deliberation on fuselage construction, the capstone team decided that a 3D printed body was more feasible and the best option for weight and cost when com-

pared to a machined aluminum body. A 3D printed body provides fast turnaround and low vibrations, and be made of lightweight, durable plastic.

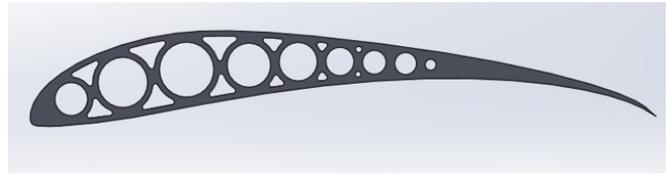


Figure 7. S1223 Airfoil



Figure 8. Fuselage Design

Due to the lack of Federal Aviation Administration (FAA) regulations on PSUAV operating altitudes, higher flight altitudes (above 100 meters) had to be considered in order to avoid any possible issues with the FAA. Due to the increased operating altitude (previous UAV models operated in the 0-100m range), it was imperative for the fuselage to be lightweight so that the wings could provide enough lift for stable flight. The team carefully selected the operating parameters based on environmental pressure, stress, velocity, altitude, ground and atmospheric temperature, and air density. The simulation for the shear stress analysis at 1500 meters is shown in Figure 9.

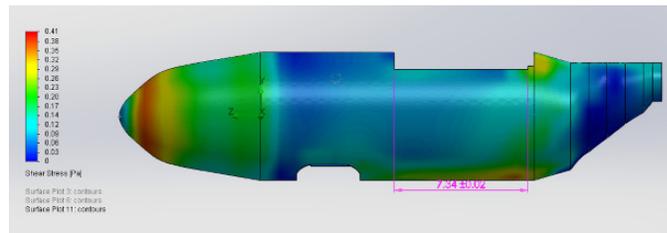


Figure 9. 1500m Shear Stress Simulation

Benefits

The members of both teams received numerous benefits from involvement with this type of capstone project that they could not get in a traditional senior design project. The

first major benefit was working on a real collaborative multi-disciplinary project that included faculty and undergraduate and graduate students from the EET and Surveying Engineering programs in the School of Technology and the ECE and ME departments in the College of Engineering. The teams also included international students. Design, construction, system integration, software, and testing, all involved other researchers instead of just the capstone team which, in turn, created new project management challenges such as teamwork, communication, documentation, and scheduling, among others, reflective of a larger-scale project in industry. Other important benefits team members received were determining real system design requirements and developing a real-world operable system. These newly acquired skill sets prepared students for industry beyond what traditional senior design projects could. Although not unique to this senior design project, but still very important, was that students obtained skills in both technical report writing and oral presentation. Each semester, the teams were required to write progress reports and give presentations. These reports consisted of many aspects of the team's progress as well as procedures that the team followed regarding safety. What was different in the reports and presentations from the traditional classroom report and presentation setting, was the audience. The audience consisted of professionals from industry as well as faculty members and fellow students. The teams received feedback from these individuals and were expected to change or explain any issue that was presented. This demonstrated to the students the level of expectation for formal report writing and presentation skills, and gave them advance experience to the expectation level they would encounter in industry. Students were also exposed to state-of-art industry tools such as CAD design and layout, dSPACE embedded controllers, National Instruments LabVIEW VFD control, PLC programming, Allen-Bradley Micrologix programming software, communication (ModBus) integration, sensor integration, fault detection, OSHA safety standards and FAA regulations, and design using SolidWorks. Students who participate in these projects would also have the technical knowledge from the use of the development tools they were exposed to during all phases of the project as well as some experience with complex system-level problem solving.

Potential industry employers and faculty sponsors also benefit from this collaboration. Potential employers will benefit from hiring graduates exposed to projects following industry-type requirements. From an industry perspective, companies are looking for graduates that are self-motivated, resourceful, can be easily integrated into a large project team, and have project critical-thinking skills. By working on a multidisciplinary project such as the case studies described in this paper, students have the potential to develop

all of these skill sets; in addition, they are forced to improve their management skills and become more accountable. These multidisciplinary teams, including international students, also prepared students with global competences. With the current globalization of engineering, industry employers expect students to be proficient in directing teams of ethnic and cultural diversity [12].

The faculty sponsoring the first project will use the test bed as a research platform for externally funded research projects in several areas such as electric drives systems, electric vehicle propulsion systems, power electronics, and ac MicroGrid, among others. The test bed was designed and built with the forethought to enable a wide variety of electric machine configurations and applications, as it provides a platform for testing of innumerable projects. In addition, the test bed will be used for undergraduate and graduate education; the test bed, at the time of this writing, is being used for two laboratory classes: Introduction to Power Electronics and Introduction to Motor Drives. The second project will be used for photogrammetric research and education, and road surveillance.

ABET Capstone Requirements and Assessment

Capstone senior design experiences are both a graduation requirement for engineering and technology majors and a requirement for ABET accreditation of these programs. The capstone or senior design experience is typically the last bridge for students between their undergraduate engineering curriculum and the engineering profession. The ABET-ETAC Criteria 5 [7] states "The Integration of Content - Baccalaureate degree programs must provide a capstone or integrating experience that develops student competencies in applying both technical and non-technical skills in solving problems." The integration of a capstone experience and externally funded faculty research projects is an effective way to actively engage students in challenging engineering design problems. In addition, the senior capstone experiences are a primary source of documentation of the achievement of ABET Criteria 3—Program Outcomes [13]. Criteria 3 requires that engineering technology programs must demonstrate outcomes (a-k), and includes: (a) an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly defined engineering technology activities; (d) an ability to design systems, components, or processes for broadly defined engineering technology problems appropriate to program educational objectives; (e) an ability to function effectively as a member or leader on a technical team; and, (g) an ability to communicate effectively. The project examples presented here suc-

cessfully satisfy all of these requirements. Project participants had the opportunity to determine real system design requirements; to work with graduate students and faculty members; to obtain both professional report writing and presentation skills; and, to be exposed to industry-leading development tools and hardware. Moreover, a broad range of educational and professional benefits results for students participating in projects that integrate capstone experiences and externally funded faculty research that focuses on real-world problems.

The assessment methodologies for this senior design course used direct and indirect measurements to assess the

applicable ABET criteria a-k. The success indicators were based on direct and indirect quantitative measures such as written reports, oral presentations, student surveys (midterm and end of semester), and instructor/student meetings. The assessment results indicated improvements in student comprehension of key concepts, and an increase in student confidence in starting their careers in industry. Table 4 shows the summary of student achievement for the student learning outcomes (SLO) and quality of instruction, as required by ABET for case study I. The results show the correlations between the project objectives and capstone requirements. All of the SLO had acceptable results, with the exception of SLO 2 (organize research and data for synthesis), which

Table 4. Summary of Student Achievement of Course Objectives and Quality of Instruction

| <i>Course Objective</i> | <i>Relates to Program Outcome(s) a</i> | <i>Assessment Instrument for This Objective</i> | <i>Standard</i> | <i>Results</i> |
|---|--|--|---|---------------------------------------|
| 1. Be able to research on applied electrical engineering technology. | 3a, degree 2 3b, degree 2 3f, degree 2 | Weekly meetings, project development phases; | 70% of students will score 70% or better. | 80% of students scored 70% or better |
| 2. Organize research and data for synthesis. | 3a, degree 2 3b, degree 2 3c, degree 2 3d, degree 2 | Weekly meetings, project phases | 70% of students will score 70% or better. | 67% of students scored 70% or better |
| 3. Prepare written reports. | 3g, degree 3 3k, degree 3 | Weekly memos, Bi-month reports, End of semester report, Final Report. | 70% of students will score 70% or better | 87% of students scored 70% or better |
| 4. Prepare and present oral reports. | 3e, degree 3 3g, degree 3 3k, degree 3 | Weekly meetings; University Expo Capstone Conference, Final oral presentation. | 70% of students will score 70% or better | 80% of students scored 70% or better |
| 5. Work in teams. | 3e, degree 3 3g, degree 3 3h, degree 3 3i, degree 3 | Weekly meetings, project development phases, oral presentations, written reports/memos. | 70% of students will score 70% or better | 100% of students scored 70% or better |
| 6. Coordinate and work to meet scheduled deadlines and facilities, manage resources, etc. | 3e, degree 3 3g, degree 3 3i, degree 3 3k, degree 3 | Project development phases, and scheduled deliverables. | 70% of students will score 70% or better | 87% of students scored 70% or better |
| 7. Learn general safety practices for test beds | 3c, degree 3 3d, degree 3 3f, degree 3 3j, degree 3 | Project design, construction, testing following OSHA requirements. | 70% of students will score 70% or better | 94% of students scored 70% or better |
| 8. Be able to make industrial type of circuit construction. | 3a, degree 3 3b, degree 3 3c, degree 3 3f, degree 3 | Project design, construction, testing, and scheduled deliverables in line with sponsor requirements and approved by sponsor. | 70% of students will score 70% or better | 100% of students scored 70% or better |
| 9. Learn how to make component selection and ordering. | 3c, degree 3 3d, degree 3 3k, degree 3 | Project design and budget requirements approved by sponsor. | 70% of students will score 70% or better | 100% of students scored 70% or better |

a. In the second column, "Relates to Program Outcome(s)...", the degrees are a way of prioritizing course outcomes. Degree 3 implies that the course places significant emphasis on that outcome, degree 2 implies moderate emphasis, degree 1 implies some but minimal emphasis.

was attributed to the lack of experience of the undergraduate students in working on research-level projects. This objective will be emphasized during the next capstone cycle. The direct measurements included technical reports and technical presentations open to faculty, students, and Industrial Advisory Board members. The students also developed a user documentation manual for the test bed. The capstone team's technical presentation scored slightly higher among three industry-sponsored capstone projects presented at the same time. The overall quality of the project received positive comments for all of the members. The test bed was used for classes and served as a demonstration project for visitors from industry and prospective students, among others.

Conclusions

The integration of funded faculty research and industry requirements in engineering technology capstone projects can provide distinctive benefits to undergraduate students, graduate students, and faculty involved in the projects. The projects of the case studies in this research study (I and II) had higher quality and a larger scale than typical senior design projects and, in this way, better resembled projects in industry and better prepared students to enter the workforce. The projects also resulted in an operable system, as opposed to traditional senior design projects. In particular, students participating in this type of project developed useful project skills, had the opportunity to be directly involved with all aspects of a complete system development cycle focusing on user needs and requirements, and followed practical industrial project standards. For the cases investigated in this study, there was no significant difference in the students' perceptions whether their capstone project was sponsored by faculty or industry, as long as the project gave the students the opportunity to develop a broad range of skills. Nevertheless, students participating in these types of faculty-sponsored projects had the potential for more employment opportunities due to the projects' similarities with industry projects. It is a reality that these projects are not available to all senior design students and probably will not become a majority in senior design. However, this is a new concept in EET programs migrating from teaching only to more research involved. Faculty-funded research projects, even in a smaller number as compared to traditional senior design projects, contribute to making EET students and faculty members more motivated and more actively involved. Most of the industry-sponsored projects in our program have relatively small budgets as compared to our case study, which could limit the complexity of industry-sponsored projects.

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TECHNOLOGY MANAGEMENT COMPETENCIES

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Abstract

In order to meet the increasing expectations of industry, technology management programs combine the application of technical skills with management competencies. The aim of the Association of Technology, Management, and Applied Engineering (ATMAE) is to develop professionals committed to solving complex technological problems, while advancing the technologist and applied engineering workforce. However, there is a wide variability of perceptions regarding the technologist and the technology manager. Clarity concerning the required competencies for an entry-level technology manager is essential. In order for technology management programs to be relevant, their competencies must be acknowledged and agreed upon. In addition, these technology management competencies must be aligned with accreditation and certification agencies within a body of knowledge. In this paper, the authors propose a set of common technology management core competencies. This research project sought to validate the competencies using reviews of literature with field, panel, and survey research. The findings indicated that the Technology Management Competency Model has both face and content validity with regard to applied and managerial contexts. Furthermore, the model identifies those competencies deemed most important by ATMAE members.

Introduction

With the increasing demands on organizations to do "more with less", and produce acceptable market results, productivity and performance standards continually raise the expectations on competitive success. To meet these expectations, organizations frequently combine the application of technical management skills with the softer skills involved in people management. Technical managers with little training or past experience with non-technical skills often perform poorly in technical management positions [1]. Because this generation lives in a highly technical environment, managers need to be proficient in dealing with knowledge workers and systems; therefore, there is a growing emphasis on the application of management competencies [2]. Additionally, as the baby boomers shift from the marketplace to retirement, experienced technical leaders will be exiting the workplace. Within the next 10 years, the U.S. will experience a greater than threefold surge in leadership turnover in engineering and technical organizations, increasing the competition for a progressively scarce re-

source [3]. Competent technical managers will be a critical success factor for organizations to stay competitive.

Given that today's labor market demands graduates competent in both technology and management, higher education has the opportunity to produce these graduates. For example, Dulaimi [4] highlighted the need for academic and professional development programs to provide the right balance of content and emphasis between the technical knowledge and the people management skills for young professionals. These technology professionals, or technologists, are described in various ways.

The National Research Council defined technology management as the link between science, engineering, and management, while ATMAE described it as the "field concerned with the supervision of personnel across the technical spectrum and a wide variety of complex technological systems" [5], [6]. The International Technology and Engineering Educators Association (ITEEA) identified the characteristics of a technologically literate person as an individual who has knowledge of processes to develop systems within practical contexts that solve problems and extend human capabilities [7]. With such a wide variance of characteristics used to describe the technologist (i.e., technical managers), a body of knowledge is not clearly defined for technology management. The authors of this current study support the development of a common technology management core with appropriate and defined competencies. The purpose of this study was to describe a core body of knowledge using competencies as a base for a technology management model. In order to accomplish the purpose, the authors asked the following questions:

- What is the core body of knowledge for an entry-level technology manager?
- What are the core competencies for an entry-level technology manager?

The "management of technology is the art and science of creating value by using technology together with other resources of an organization" [8]. A technology manager should have: 1) some minimum level of technical knowledge; 2) skills in one or more contextual areas; and, 3) applied abilities in system design, application, products, or processes [9]. Technology managers must have certain competencies that are agreed upon and measurable. At the university level, technology management programs are distinctly different from engineering or engineering technology programs (e.g., mechanical, electrical, civil, etc.). A re-

quired management curriculum is what distinguishes ATMAE-accredited four-year programs from two-year programs [10]. Minty [11] asserted that historical comparisons of the technological and managerial perspectives are closely aligned.

In order for technology management programs to succeed, they must produce graduates who possess the requisite knowledge, skills, and abilities (KSAs). The mission of the Association of Technology, Management, and Applied Engineering (ATMAE) is to solve complex technological problems and develop the competitive technologist and applied engineering workforce. The *ATMAE Accreditation Handbook* [10] lists content areas such as quality, finance, accounting, safety, legal, project management, and other courses consistent with the definition of industrial technology. Of these, what competencies are most important for a technology manager? Are there others? Without a recognized and accepted body of knowledge for technology management, the discipline of industrial technology, applied technology, and applied engineering will continue to be confused with other technical disciplines. Clarity regarding the required competencies for an entry-level technology manager is imperative.

Review of Literature

The need for a body of knowledge for technical-professional competencies is well documented, particularly with the advent of outcomes-based accreditation and industry's desire for certified employees (e.g., SME, ASQ, APICS, PMI, etc.). Meier et al. [12] and Meier and Brown [13] summarized the competencies essential for the success of new employees. Calhoun [14] created the Health Leadership Competency Model that identified outcomes, appropriate behaviors, and core technical-managerial competencies. Rifkin et al. [15] developed a competency model containing a hierarchical framework of the technical manager's role, critical accomplishments, work activities, skills, knowledge, and personal attributes. Other published literature regarding management competencies includes manufacturing and industrial management, general management, safety, project management, retail management, and sports administration [16-29].

As organizations advance technologically, the need for technical leaders will be vital. In benchmark companies like Rockwell Automation and GE Healthcare, the identification and development of the next generation of technical leaders is crucial [30]. Promoting individuals based solely on technical knowledge is becoming more difficult due to the need for sound managerial decisions across technically complex environments. Nair et al. [31] found a competency gap be-

tween engineering traits of graduates and the expectations of employers. They asserted that students need a combination of technical (hard), managerial (soft), and global (multicultural communication) competencies in order to be successful. Additionally, the Society of Manufacturing Engineers' (SME) Manufacturing Education Plan: Phase 1 and Phase 3 reported the following competency gaps in order of importance: business knowledge skills, project management, written communication, supply chain management, oral communication, international perspective, quality, problem solving, and teamwork [32], [33]. The proficiency of graduates is measured by entry into the job market and long-term career success. Education and professional development increase the proficiency of graduates and close the competency gaps.

Historically, higher education focused on the education process or the inputs into the systems. Now, higher education is increasingly asked to provide student outcomes or competencies [34]. At the university level, "Technology Management programs typically include instruction in production and operations management, project management, computer applications, quality control, safety and health issues, statistics, and general management principles" [10]. Increasingly, competencies are the basis for determining if programs are offering appropriate content and if students are meeting the competency criteria. Both ATMAE and ABET (the Accreditation Board for Engineering and Technology) [35] accreditations are based on students acquiring specific competencies, as measured by student outcomes.

The development of a common body of knowledge for technology management provides the rationale for a common core that distinguishes ATMAE-accredited four-year and graduate programs. Thus, a conceptual model is useful when attempting to describe the common elements. The American Society for Quality (ASQ), the Association for Operations Management (APICS), and the Project Management Institute (PMI) all have well-recognized bodies of knowledge for their professional constituents. However, ATMAE accrediting standards do not specify a core body of knowledge for management, only a range of required hours (12-24) and a broad list of potential subjects. In addition, the current content areas of production planning and control, quality, safety, and management on the Certified Technology Manager (CTM) exam are not aligned with the accrediting standards or with a recognized body of knowledge for technology management. Although there are ongoing revisions to both accreditation and certification standards, there is no coordinated effort to align these with a recognized body of knowledge.

Using published literature and previous studies, a common perspective of technology management is attainable

within the discipline. However, as Minty [11] explained, this must be undertaken with knowledge that technology management is neither grounded in general business nor engineering, but is a unique body of knowledge grounded in socio-technical management. The term socio-technical refers to people and technology (or systems) [11]. Engineering and industrial technology programs have used terms associated with socio-technical theory such as six sigma, continuous improvement, autonomous teaming, and re-engineering [36]. Socio-technical systems reveal the interdependence of technology, people, the external environment, and the design of work [37]. As the authors gathered the information for a socio-technical framework, it was necessary to determine the appropriate competencies.

Competency modeling is an organized structure for defining the KSAs that students need to know in order to be proficient in their field of study and ultimately their career. Competence is a function of performance that goes beyond knowledge. Competencies can be defined as observable behaviors exhibited by technical managers that are successful, both in terms of their results and the process or behavior for enabling those results [38].

Methodology

Phase One Model Development

The ATMAE Management Division formed a panel sub-group in 2010 to begin to define a technology management set of core competencies. The sub-group developed an initial competency model based on the group's interaction with industry, personal industry experience, and academic experience in technology management. The initial model was presented to industry professionals, group networks, advisory board members, and ATMAE members in 2011. In addition, the competency model was benchmarked against existing literature and research. This method was congruent with accepted approaches to competency model development that included selecting competencies from lists to field research. The panel method of research is a group of experts collaborating to develop a set of competencies [39].

After multiple revisions, based on input from educators, industry professionals, and research, a high-level technology management model was developed. The model showed the generic entry-level competencies for a technology manager within a category of knowledge for a specific managerial context. The competencies are applicable to systems, operations, processes, or projects and linked throughout by accepted leadership principles; see Figure 1 for an overview of the initial model.

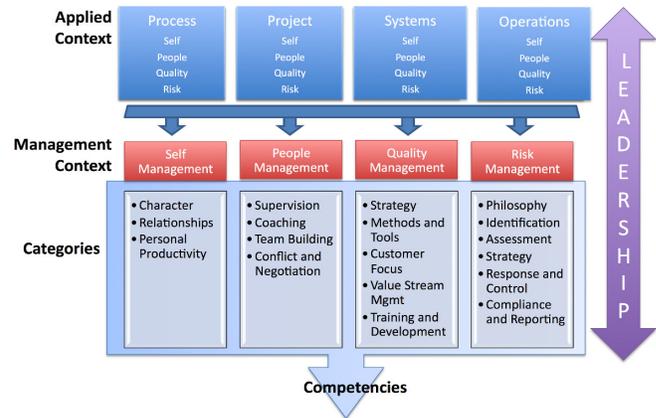


Figure 1. Initial Technology Management Competencies Model

To understand the model, it is important to define the contexts that are the situations or environments to which the competencies are applied. The project and process environments are most familiar with projects being the one-time application of processes to produce a unique product or service. Systems refer to the management of technology across disciplines and companies in an integrated fashion for the purpose of business venture and development, such as supply chain management. Operations are the management of technology within a specific specialty. Common industrial contexts would include those listed by the Bureau of Labor Statistics such as manufacturing, construction, telecommunications, or retail trade [40]. It is the assertion of the authors that the same competencies are utilized regardless of the applied context and can be classified into four management areas. The managerial context areas are self-management, people-management, quality-management, and risk-management, and are well-supported in literature. While the literature may refer to them using slightly different terms, they are frequently mentioned in leadership and management writings. For example, it is well accepted that in order to lead people effectively, managers must be able to manage themselves [41].

The other two threads that run consistently through the literature are managing quality and risk. Quality is a primary focus in the management of any endeavor, particularly technology, and is regularly ranked as a principal competency in literature. The management of risk is less familiar, but is still represented strongly in management theory. As related to process, project, systems, or operations, the assessment of risk and mitigation of uncertainty is applied to design, research, production processes, product development, mergers, and acquisitions from both quality and financial perspectives. For example, the National Aeronautics and Space Administration's (NASA) Leadership Development Program (LDP) measures results in three general areas: 1)

mission success as substantial risk involved in space exploration, 2) project success through improved team leadership, and 3) organizational advancement within the NASA system [3].

Within each management context, the initial specific competencies were sorted into generic and recognizable themes. They are purposely broad to allow for flexibility and interpretation. The competencies may have popular synonyms that could be justifiably used instead. The intent of the model and initial competencies was to establish a baseline for further refinement; see Table 1 for the complete list of initial competencies sorted by category theme.

Phase Two Model Development

In order to refine the initial Technology Management Competencies Model, the authors developed a survey in February, 2012, that asked respondents to rank the importance of the competencies in defined contextual areas. The survey population was approximately 700 ATMAE members who were invited to participate using the professional member listserv. The ATMAE listserv consists of all ATMAE members who can send and receive email in order to share and gather information on current developments in the field of technology, technology management, and applied engineering.

The survey links were available for approximately four weeks. After weeks 1 and 2, a follow-up email reminder was sent. Qualtrics, a third-party survey software provider, automatically collected 93 anonymous responses. At the end of the survey period, 66 surveys were fully completed and validated (9-13% response rate). In April, 2012, faculty and industry professionals from engineering, engineering technology, technology, operations management, and advisory boards outside of ATMAE were invited to participate. Additional responses were collected until May, 2012, resulting in 124 total responses of which 75 were fully completed surveys.

Prior to the survey, participants were given a glossary of relevant terms. This was followed by questions that asked participants to check the competencies applicable to each context. The glossary of terms follows:

Technology Management Applied Contexts

- Operations—Management of technology within a specific industrial specialty.
- Systems—Management of technology across disciplines and companies in an integrated fashion for the purpose of business venture and development.

- Project—The one-time application of a process to produce a unique product or service.
- Process—The transformation of input elements into output elements with specific properties, within defined parameters or constraints.

Table 1. Initial Competencies by Category Theme

| Self-Management Competencies | People Management Competencies | Quality Management Competencies | Risk Management Competencies |
|---|--|--|--|
| Character Values Integrity Responsible Capable Enthusiasm | Supervision Planning Organizing Staffing Leading Controls/ reporting Resource allocation Decision -making Listening | Philosophy Methods and Tools Frameworks Standards Customer focus Strategic planning Resources Measurement Training and development | Philosophy Culture and context Objectives Risk tolerance/ appetite |
| Relationships Communication Cooperation Emotional/ Social Spiritual Trust Influence | Team Building Mentoring Counseling Appraisal | Process Management Process design Control Improvement Value Stream Constraints | Identification Opportunities Tools and techniques Risk taxonomies |
| Personal Productivity Motivation Resourcefulness Discipline Knowledge Passion Vision | Coaching Facilitation Problem solving Group dynamics | Methods and Tools Lean sigma Safety and ergonomics Statistics SIPOC and PDCA Reliability | Assessment Analysis Drivers Prioritization |
| | Change Alignment Empowerment Respect Support | | Treatment Treatment selection Action planning/ Mitigation |
| | | | Response and Control Policy deployment Governance Evaluation Compliance and reporting |

Technology Management Managerial Contexts

- Quality Management- The use of quality assurance and control of processes and products to achieve consistent and predictable quality.
- Risk Management- The identification, assessment, and prioritization of risks followed by coordinated

and economical application of resources to minimize, monitor, and control their probability and/or impact.

- *Self-Management*- Methods, skills, and strategies by which individuals can effectively direct their own activities toward the achievement of goals and objectives.
- *People Management*- The deployment and handling of human resources to work together to accomplish desired goals and objectives using available resources efficiently and effectively.

Findings

Question 1. Select the applied context(s) of technology management. Select all that apply.

The purpose of this question was to validate the applied contexts. A total of 99 individuals responded to the question (see Figure 2). Eighty-four percent of the respondents checked systems and projects, while 83% checked processes and operations.

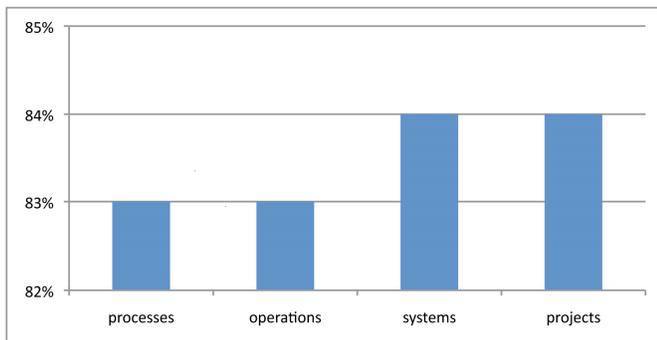


Figure 2. Applied Context of Technology Management

Question 2. Select the management context(s) that are applied to processes. Select all that apply.

The purpose of this question was to determine if quality management, risk management, people management, and self-management is applicable to processes. Seventy-seven individuals responded to the question (see Figure 3). Ninety-nine percent of the respondents checked quality management and 81% checked people management. Seventy-three percent checked risk management, while 55% checked self-management.

Question 3. Select the management context(s) that are applied to systems. Select all that apply.

The purpose of this question was to determine if technology management in the areas of quality, risk, people, and self is applicable to systems. Seventy-six individuals responded

to the question (see Figure 4). Ninety-two percent of the respondents checked quality management and 80% checked people and risk management. Forty-two percent checked self-management.

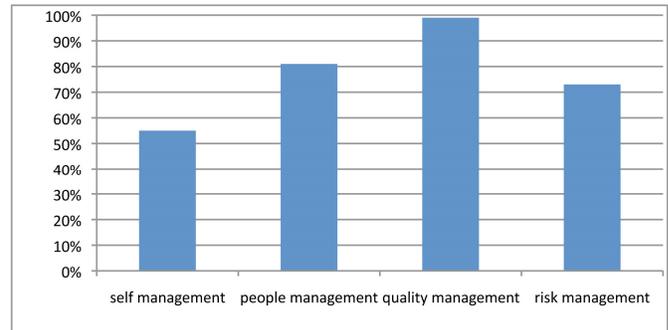


Figure 3. The Applicability of Specific Technology Management Contexts to Processes

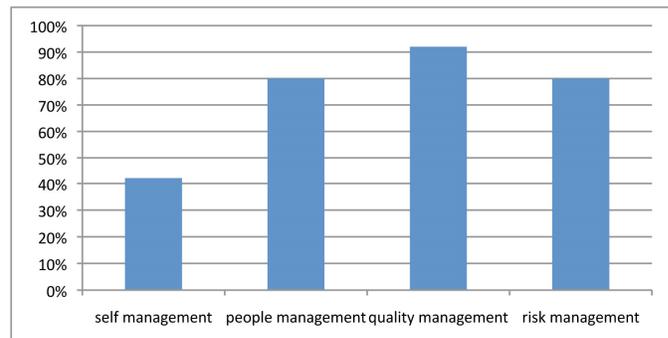


Figure 4. The Applicability of Specific Technology Management Contexts to Systems

Question 4. Select the management context(s) that are applied to operations. Select all that apply.

The purpose of this question was to determine if technology management in quality, risk, people, and self is applicable to operations. Seventy-five individuals responded to the question (see Figure 5). Ninety-two percent of the respondents checked people and quality. Seventy-seven percent checked risk management. Fifty-nine percent checked self-management.

Question 5. Select the management context(s) that are applied to projects. Select all that apply.

The purpose of this question was to determine if technology management in quality, risk, people, and self is applicable to projects. Seventy-six individuals responded to the question (see Figure 6). Eighty-nine percent checked people and 88% checked quality. Seventy-six percent checked self-management and 71% checked risk management.

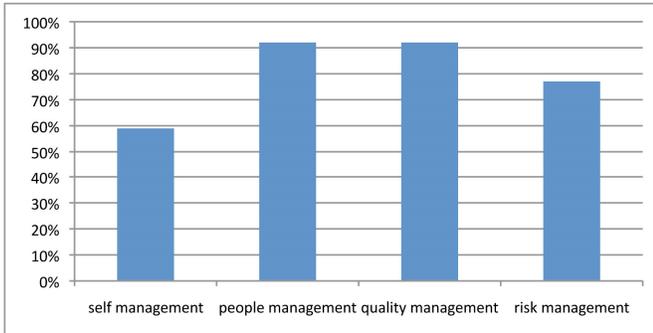


Figure 5. The Applicability of Specific Technology Management Contexts to Operations

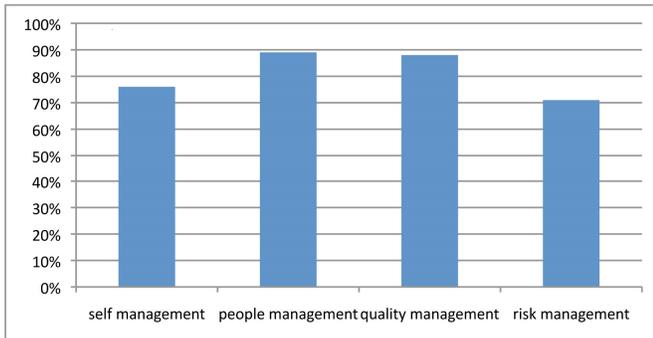


Figure 6. The Applicability of Specific Technology Management Contexts to Projects

Respondents were then given the opportunity to select the applicable entry-level technology management competencies in each of the management contextual areas (e.g., quality, risk, people, and self). These competencies were drawn from the initial Technology Management Model. Each contextual management area listed between 16 and 19 generic competencies and included a field labeled *other*, where respondents could add additional competencies. The purpose of these questions was to validate or refute the competencies and determine those perceived most important. For the contextual areas of self-management, people management, quality management, and risk management, the number of responses was 74, 72, 71, and 71, respectively.

Question 6. Select the following competencies that apply to self-management. Select all that apply.

In Figure 7, the percentage of responses is sorted from highest to lowest. Additional responses equating to five percent of the respondents were added: innovative, ethical, monitoring quality or the ability to discern quality, family, company, and society.

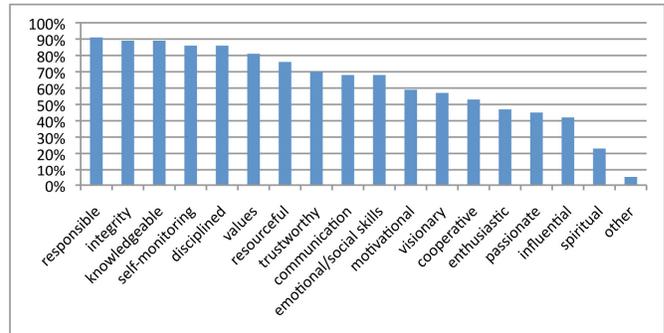


Figure 7. Applicable Self-Management Competencies Sorted by Percentage of Responses

Question 7. Select the following competencies that apply to people management. Select all that apply.

The sorted percentage of responses is shown in Figure 8. Additional competencies were added equating to four percent of the responses: open communications, training and development, personal needs, company, and society.

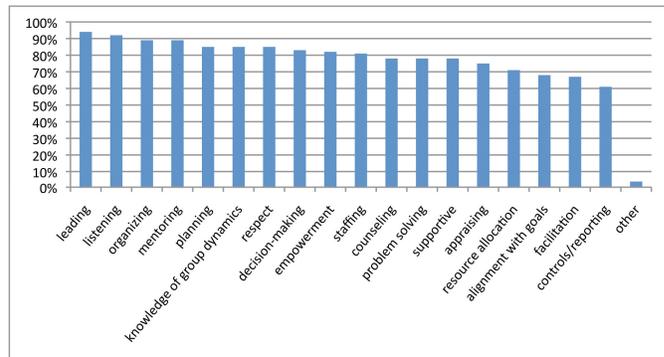


Figure 8. Applicable People Management Competencies Sorted by Percentage Response

Question 8. Select the following competencies that apply to quality management. Select all that apply.

The sorted percentage of responses is shown in Figure 9. Additional responses equating to four percent of respondents were added: teaming, benchmarking, communication, documentation/ISO 9000, compensation systems, ethics, tools of Ishikawa in addition to SPC, assessment, etc.; TQM is more than control or assurance; innovation, finance, environment, and responsibility.

Question 9. Select the following competencies that apply to risk management. Select all that apply.

The sorted percentage is shown in Figure 10. Three percent of respondents added that all of the above apply, but

also that some are more important than others, such as people, society, and environment.

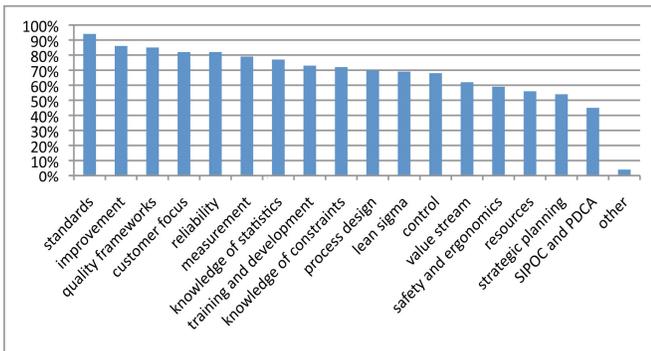


Figure 9. Applicable Quality Management Competencies Sorted by Percentage Response

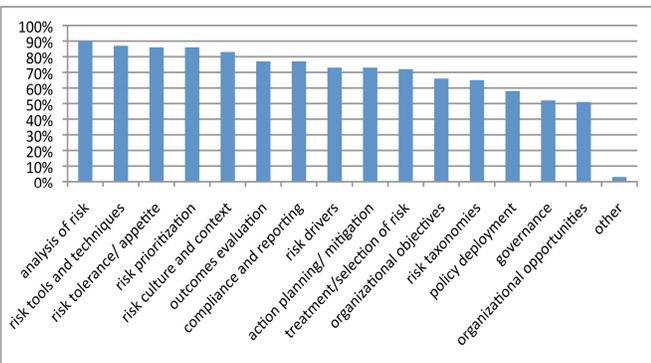


Figure 10. Applicable Risk Management Competencies Sorted by Percentage Response

The Technology Management Core Competency Model

Based upon the survey, a revised version of the Technology Management Competencies Model was created. The Technology Management Core Competency model is shown in Figure 11. It shows the generic entry-level competencies for a technology manager for a specific managerial context. The competencies are applicable to systems, operations, processes, and projects and linked throughout by accepted leadership principles. The findings indicate that the Technology Management Core Competency Model has both face and content validity, particularly with regard to the applied contexts of process, project, systems, and operations.

Respondents overwhelmingly agreed on the applied contexts. In terms of the quality, people, risk, and self-management contexts, a majority of the respondents agreed

that they apply to process, project, systems, and operations. The only exception was the applicability of self-management to systems (defined as the management of technology across disciplines and companies in an integrated fashion for the purpose of business venture and development). However, over two-fifths of the respondents perceived a degree of applicability. Thus, the applied and management contexts of the model appear to have support from academic and industrial communities. The responses between the ATMAE and non-ATMAE participants were not significantly different.

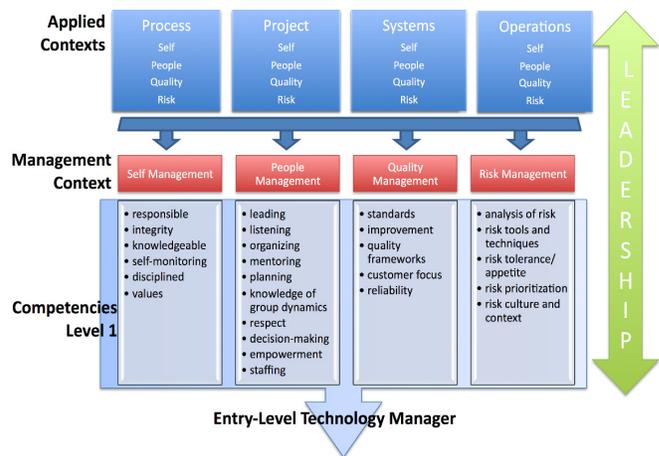


Figure 11. Technology Management Core Competency Model

The perceived relevance of the individual competencies varied. Any competency receiving less than a response of 50% was removed. The greatest response variation (23% to 91%) of the competencies was in the self-management context. The least response variation of competencies was in people management (61% to 94%). All competencies for risk and people management had greater than a response of 50%. For self-management, four competencies received less than 50% response. For quality management, only one competency received less than 50% response. Using the level of response, the authors then stratified the competencies.

The entry-level competencies for technology management are shown in Table 2. Competencies receiving a response of greater than 80% were categorized level one. Competencies receiving between 60% and 80% were designated level two, and competencies greater than 50% but less than 60% were labeled level three. This stacked ranking keeps the importance of the competencies at the forefront for outcomes assessment and reinforces the critical entry-level KSAs of technology managers. The competencies are purposely broad to allow flexibility, interpretation, and justification for the use of popular synonyms.

Table 2. Technology Management Core Competencies

| Level | Competencies | | | |
|-------|---|---|--|--|
| | <i>Self-Management</i> | <i>People Management</i> | <i>Quality Management</i> | <i>Risk Management</i> |
| 1 | responsible integrity knowledgeable self-monitoring disciplined values | leading listening organizing mentoring planning Knowledge of group dynamics respect Decision-making empowerment Staffing | standards improvement Quality frameworks Customer focus reliability | analysis of risk risk tools and techniques Risk tolerance/appetite Risk prioritization risk culture and Context |
| 2 | resourceful trustworthy | counseling Problem solving supportive appraising Resource allocation | measurement Knowledge of statistics training and development Knowledge of constraints Process design | Outcomes evaluation Compliance and reporting risk drivers action planning/mitigation Treatment/selection of risk |
| 3 | communication/ emotional/ social skills motivational visionary Cooperative | Alignment with goals facilitation Controls/reporting | lean sigma control value stream safety and ergonomics resources Strategic planning | Organizational objectives Risk taxonomies Policy deployment governance Organizational opportunities |

Implications of the Research

ATMAE sets standards for academic program accreditation, professional certification, and development for educators and industry professionals involved in technology, leadership, and systems design [42]. The development of a common and recognized body of knowledge for the discipline starts with an understanding of technology management competencies. The operational effectiveness of accredited technology management programs depends on identifying competencies, measures, and outcomes. An agreed-upon set of technology management competencies tied to a body of knowledge will strengthen the discipline. In particular, the ATMAE Management Division must lead in the adoption of the technology management competencies and the corresponding body of knowledge. ATMAE membership and industry advisory boards should ratify and adopt these tech-

nology management competencies. The critical competencies within a body of knowledge should be congruent with ATMAE standards and certification. ATMAE should recognize and incorporate these competencies into accreditation and the Certified Technology Manager exam.

Although there is still much work needed to develop a comprehensive body of knowledge for technology management, efforts can now begin using the identified competencies as a starting point. Future research should capture and analyze the seminal published works regarding technology management and the textbooks being assigned by accredited ATMAE technology management programs. This starting point will provide the relevant body of knowledge needed to achieve the competencies. Additional areas of opportunity will be the development of measures and outcomes for the technology management competencies. This will close the loop for outcomes assessment and technology management program accreditation. The authors recognize that developing measures for these competencies will be difficult. However, both industry and academia use performance-based appraisals based on similar competencies. The field is ripe for further research and creative solutions.

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A CASE STUDY OF THE GLEN ACRES UNIVERSITY / COMMUNITY PARTNERSHIP: REDUCING ENERGY CONSUMPTION IN EXISTING HOUSING

Mark Shaurette, Purdue University

Abstract

Existing building stock in the developed world is responsible for approximately 40% of all energy consumption. Replacement of the existing built environment with more efficient structures is not only impractical but also abandons much of the embodied energy already present in the extant materials. As a result, attempts to significantly reduce the operational energy consumption in existing buildings must be based on a combination of energy-related retrofitting of existing buildings and behavioral changes by the building's occupants.

Due to the common attributes of existing residential buildings, this sector offers large-scale opportunities for energy-related retrofitting. Nevertheless, while the technologies for insulation, climate control, lighting, consumer appliances, and water consumption common to domestic structures are often similar within communities, many complicating factors exist which limit production-scale energy retrofits.

Unlike new housing construction which has, in many parts of the world, become uniform and systematized, energy-related housing retrofitting is done on a per-house basis and continues to be restricted in scope. The limitations stem from a fragmentation of ownership, a dearth of construction organizations offering whole-house energy retrofitting as a primary service, limited funds to advance the process, and housing valuation practices that fail to recognize the value created by energy-related retrofitting.

In this paper, the author presents a detailed examination of a community-wide energy retrofitting project which was financed using stimulus funds from the U.S. government and distributed to a small community adjacent to a major research university. The original concept of market transformation for energy retrofitting expected from the program is presented along with the university's participation in program design, program management, related educational activities, student involvement, and resulting benefits to both the university and the community. In addition, some unexpected challenges which continue to constrain market transformation for energy retrofitting are included.

Introduction

Buildings are tremendous users of electricity, accounting for more than 72% of electricity use in the United States. This contributes 39% of the carbon dioxide (CO₂) emissions in the United States per year, more than either the industrial or transportation sector of the economy [1]. Adopting energy conserving measures and alternative sources of energy production for use in buildings offers vast opportunities for reaching the national goal of energy independence and reducing climate change.

An October, 2008, report by the National Science and Technology Council entitled the Federal Research and Development Agenda for Net-Zero Energy, High Performance Buildings notes the general lack of informational guides and incentives, and the misinformation that exists about energy consumption in buildings [2]. The report recommends effective technology transfer through improved tools and guides, education and training, and market-based building valuation metrics. The basis for this technology transfer would be research and demonstration coupled with private industry activity. In this paper, the author describes a program that serves as a vehicle for the suggested education and technology transfer specifically targeting residential properties and the conditions encountered in the State of Indiana, USA.

The City of Lafayette, located in a small metropolitan area of less than 200,000 residents, was awarded a grant from the U.S. federal government for approximately 80 energy-conserving retrofits in the Glen Acres and Vinton communities through a retrofitting ramp-up program. Lafayette administered these funds through the use of staff currently employed under a Comprehensive Neighborhood Revitalization Fund for Glen Acres. The fund for this Neighborhood Stabilization Program (NSP) financed the acquisition of foreclosed properties that were rehabilitated for sale to low-income individuals. As the primary outreach vehicle for the retrofitting ramp-up program, this NSP funding facilitated the acquisition of a home for a deep-energy retrofitting demonstration.

The neighborhoods of Glen Acres and Vinton are comprised of starter homes built between 1950 and 1970. A

significant challenge for market transformation in these communities was the limited ability to communicate directly with homeowners. Because Glen Acres and Vinton are conventional post World War II first-ring suburban communities, no community center or other social meeting place is available for marketing outreach. As a result, no venue existed for the purpose of educating homeowners about the benefits of energy-conserving retrofits or available opportunities for grant assistance to implement appropriate retrofits for low-income homeowners.

As part of the Lafayette program, ultimately named the Lafayette Energy Assistance Program (LEAP), outreach opportunities and potential for homeowner education was provided by a high-profile, deep-energy retrofitting demonstration home located within the Vinton community. The use of a deep-energy retrofitting demonstration home within the community provided marketing outreach needed to encourage participation by community homeowners. Locating the home within the community helped to make grant implementation convenient for the community within a location appropriate for social interaction, and provided a path for bringing the retrofitting program message to individuals who may not be exposed to it in the mass media. The demonstration used in that situation established energy conservation retrofitting strategies as well as alternative energy sources, some of which were beyond the current capability of participating homeowners to adopt, and to draw as large an audience as possible. The program exposed homeowners in the target neighborhoods and the larger Lafayette community to currently available retrofitting technologies as well as available grant incentives.

In a December, 2010, review of U.S. whole-home retrofitting programs, the National Home Performance Council noted that utilities sponsored the majority (113) of the 126 whole-home retrofitting programs identified in the study. Of this group, 38 met the home performance guidelines of the Energy Star program sponsored by the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) [3]. To receive a Home Performance designation under the Energy Star program, all of the following components must be included in the program. Similar components were used for the LEAP, specifically:

1. An assessment of the home by a certified energy specialist using visual and diagnostic methods;
2. A set of recommendations for improving the home based on the assessment;
3. Assistance for homeowners in identifying contractors who can implement the recommendations;
4. Verification that work was performed and that health and safety issues were addressed; and,
5. Quality assurance measures.

The following narrative presents a synopsis of the Lafayette Energy Assistance Program (LEAP), how it was conceived for funding by the U.S. Department of Energy (DOE), and basic program implementation. The presentation of case study material introducing the program description and a narrative discussion of steps taken by local program administrators is intended to be instructive for those wishing to develop and implement similar community-scale retrofitting programs. This case study was limited to the experiences of the author, who has served as technical advisor to the City of Lafayette during the initial funding request period and program administration.

Partnership Funding and University Participation

As part of the economic stimulus program in 2009, the U.S. government chose energy efficiency as an area where federal funds could be expended to achieve multiple goals. The funds appropriated by the American Recovery and Reinvestment Act of 2009 were primarily intended to stimulate the economy and create jobs. The Energy Efficiency and Conservation Block Grants (EECBG) Program, funded for the first time by the Recovery Act, supported a presidential priority to promote energy efficiency and the use of renewable energy technologies. Using up to \$453.72 million in Recovery Act EECBG funds for a funding opportunity announcement (FOA), the Retrofitting Ramp-up Program was initiated [4].

Purdue University saw the Retrofitting Ramp-up Program as an opportunity to utilize the skills and resources available in the College of Technology Department of Building Construction Management to assist the limited staff available in the City of Lafayette in obtaining support from this funding opportunity. The City of Lafayette's close proximity to campus and recent collaboration to seek funding from the State of Indiana for an energy-related retrofit demonstration home, which generated interest but was not funded, led to a partnership to develop a Retrofitting Ramp-up proposal. Although Lafayette was eligible to receive funding, it was necessary to team up with the City of Indianapolis, the nearest major metropolitan area, to generate a funding request large enough to meet the program requirements.

The proposal was chosen as one of 25 awards throughout the U.S. in April of 2010. Indianapolis received a grant totaling \$10 million of which just over \$1 million was allocated to the City of Lafayette. Although no grant funds could be expended beyond April of 2013, delays in final program guidelines from the Department of Energy prevented the agreement between Purdue University and the City of Lafayette.

ette from being drafted until late summer of 2010. Purdue University, as a subcontractor to the City of Lafayette, a sub-grantee, was relieved from many of the reporting requirements of the program but retained a substantial requirement to assist the city as the primary advisor to the program.

The City of Lafayette community development and redevelopment departments cooperated in choosing a neighborhood for the retrofitting ramp-up that would facilitate community-wide housing retrofit for improved energy performance. Retrofits would be funded through grants to low-income homeowners with the deep-energy demonstration of housing retrofitting serving as a highly visible example of possible outcomes in a typical neighborhood home. The Glen Acres and Vinton communities are located in an area with a significant number of foreclosed post World War II homes that are appropriate for energy retrofitting. Funds from a U.S. government Neighborhood Stabilization Program (NSP) grant to the City of Lafayette for a comprehensive redevelopment of the same communities was used to allow the necessary city planning staff to complete the project.

The NSP funding was intended to finance the acquisition of foreclosed properties that were then rehabilitated for sale to low-income individuals. This financing provided the means for Lafayette to purchase a deeply discounted home in foreclosure that would serve as the basis for the deep-energy retrofitting demonstration. The two programs had different but compatible goals. The DOE Retrofitting Ramp-up Program [4], later renamed Better Buildings, had the following major goal:

To stimulate activities that move beyond traditional public awareness campaigns, program maintenance, demonstration projects, and other 'one-time' strategies and projects ... to stimulate activities and investments which can 1) Fundamentally and permanently transform energy markets in a way that make energy efficiency and renewable energy the options of first choice; and 2) Sustain themselves beyond the grant monies and the grant period by designing a viable strategy for program sustainability into the overall program plan. (p.7)

Others have noted the urgency of energy market transformation that is outlined in the Retrofitting Ramp-up funding opportunity because "The full deployment of cost-effective, energy-efficient technologies in buildings alone could eliminate the need to add to U.S. electricity-generation capacity" [5]. In contrast, the NSP funding goals sought to stabilize neighborhoods experiencing significant foreclosure activity through community infrastructure improvements

and elimination of vacant housing units. The NSP directly funded housing renovation or, in some cases, demolition. Because NSP funds were available to improve both the physical condition as well as the current market viability of the home selected for the deep-energy retrofitting, the demonstration home was able to showcase the cosmetic and lifestyle upgrades often chosen by homeowners along with the energy-related retrofits being funded under the DOE program. Combining these two grants provided a showcase for a whole-house view of refurbishment services. Whole-house retrofits provide savings in cost and complexity by completing energy-conserving measures, while at the same time repair or cosmetic upgrades are implemented. A significant example of this was experienced in this case of the deep-energy demonstration home. Air sealing and insulation upgrades were completed with lower cost and complexity because the exterior siding for the home was already being replaced.

Technical research for selection of energy-conserving measures (ECM) was carried out for the deep-energy retrofitting demonstration by faculty and graduate students at Purdue University in order to assess energy-reduction potential and impacts on occupant comfort. Although limited field studies have been carried out to establish standards for thermal comfort in residential structures [6], it was considered an important facet of ECM selection. In parallel with the technical research, a weekly meeting was held with the builder and the NSP program manager. The ECM selection was based on the following guiding principles.

1. ECMs should be appropriate for most homes in the communities as follows:
 - Easy for local building trades to understand and install.
 - Materials available through traditional supply channels without delay.
 - Performance of ECM assessed from a whole-building viewpoint.
 - Near-term potential for positive payback but with no specific cutoff.
 - Priority given to retrofits that could be funded by program grants.
 - Promote energy conservation first with introduction of alternative energy sources only when energy consumption has been minimized.
2. ECMs obvious to visitors and individuals that passed by the demonstration home were desirable for program visibility and ease of endorsement.

The combined management of the NSP funding and the DOE funded grants for the Lafayette Energy Assistance

Program created a positive synergy. Nevertheless, the local program manager initially involved with the NSP program possessed little knowledge of building technology or energy-related construction and, at times, exercised poor financial management. Delays resulted that prevented the construction activity from progressing at a normal pace. Because of these delays, it was not possible to use the demonstration home as originally intended. A change in the program manager position by the City of Lafayette was made after approximately six months, but LEAP was already well behind schedule.

The intended use of the demonstration home was to provide LEAP marketing outreach. Glen Acres and Vinton are communities with substantially more low-income and minority residents than the overall Lafayette population and no venue exists within the communities for the purpose of educating homeowners about the benefits of energy-conserving retrofitting or available opportunities for assistance in financing and implementing appropriate retrofits for their homes. The construction delays prompted the feeling that the demonstration home alone could not be counted on as a source of community outreach. To overcome this possible shortcoming, signage at the building site, frequent public service press and radio releases through Purdue University press outlets, meetings at a community school advertised by neighborhood signage, and word of mouth from early grant recipients helped to keep the grant program on track.

The Deep-Energy Retrofitting Demonstration Home

A detailed description of the ECMs chosen for the demonstration home is beyond the scope of this paper. The following list provides basic information about the ECMs.

| | |
|-----------------|---|
| Windows: | R-5.56 triple glazed casement |
| Sun Tube: | One in each bath with dimmer to provide daylight illumination |
| Exterior Doors: | Insulated steel, thermal break frame, magnetic weather-strip, polyurethane core R-8.3 |
| Crawl Space: | Damp Proof w/ sealed 20 mil poly floor cover |
| Attic Access: | R-40 insulated, weather-stripped attic closure system |
| Air Seal: | Air seal all top plates and ceiling penetrations with closed cell foam & Expanding foam seal all exterior wall penetrations |
| Insulation: | Attic – R-60 Loose Fill Cellulose 3" closed cell foam - 3' at roof edge (R- |

| | |
|-----------------------------|--|
| | 20+) Crawl Space – 2" closed cell foam on interior of crawl wall and band joist (R-13+) Exterior Walls – R-11 batts @ 2x3 wall cavity plus 4" (R-20) extruded polystyrene sheathing (2 layers of 2" foam with lapped and taped joints) |
| South Overhang: | Extend to 16" for summer shading and add continuous vent |
| Hot Water: | Heat Pump Water Heater min. COP rating of 2.0 or greater |
| Renewable Energy: | Nominal 4 KW Solar PV System |
| Furnace & AC: | Multi-speed air handler, min. 25,000 BTU gas furnace, 1 ton AC Mastic Seal All Ductwork |
| Energy Recovery Ventilator: | Min. 60% heat recovery, unit and ductwork installed in conditioned space |
| Thermostat: | 7-Day Setback |
| Appliances: | Washer – Front Load, Energy Star Rated Dryer – Energy Star Rated Refrigerator – Top Freezer, Energy Star Dishwasher – Energy Star Rated |
| Lighting/Electrical: | 44 circuit energy monitor, real-time Internet enabled energy use dashboard All lighting CFL or T-8 fluorescent except LED kitchen task lighting |
| Window Coverings: | Living Room Insulating Cellular Shades with air sealing tracks |

Because the deep-energy retrofitting home was also an NSP remodel project, the builder chosen to complete the work was a low bidder under the qualification rules of NSP funding. They had a typical background in residential construction with no special expertise in energy-related buildings. The weekly meetings used in the ECM selection process were an opportunity to provide the builder and some of his subcontractors with the technical requirements of the most unusual of the ECMs. A Ph.D. student made weekly visits to the project site to meet with the builder, the program manager, and any subcontractors or material suppliers involved that week. With the builder in charge of day-to-day work and quality control, occasional performance issues were anticipated.

While no serious quality control issues were apparent, several things did occur that were indicative of common oversights that could be experienced in energy-related retrofits. To verify the energy performance of the demonstration house, an energy auditing firm was hired to complete a post-construction inspection using a blower door and duct blaster

to confirm the success in air sealing the structure and duct-work. A preliminary use of the blower door was also utilized before completion of the interior wallboards. At this point, the ceiling was complete and all air sealing measures were completed by the builder's subcontractors. Within a very short period of introducing negative air pressure to the structure, significant flows of cold exterior air were noted entering. Figures 1 and 2 are examples of a few of the many poorly sealed penetrations.

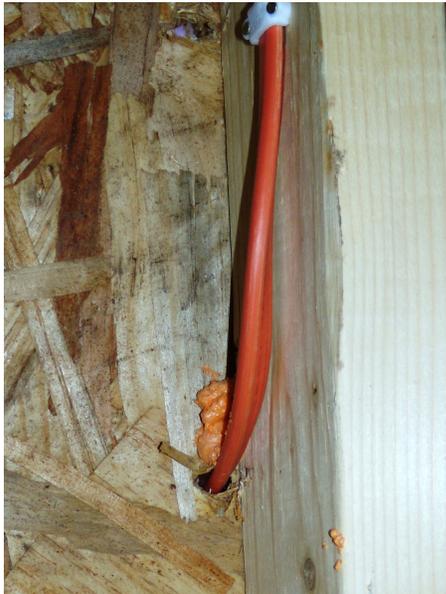


Figure 1. Poor Foam Air Sealing



Figure 2. No Foam Seal at Exterior Penetration

Failure to commission HVAC equipment is common in residential construction. It was no different in the demonstration home. The first time the air conditioning was turned on, the air volume from the air handler was so high that it caused significant noise within the home and caused papers to blow if located close to an air supply outlet. The multi-speed fan for the system was capable of servicing a range of capacities from 1.5 to 6 tons of cooling. Rather than setting the system for the design parameters, the HVAC installers left the factory preset values in place.

In addition to verifying the air infiltration and duct leakage of the completed demonstration home retrofitting, the energy auditing firm completed a common U.S. home energy rating called the Home Energy Rating System (HERS). The HERS rating is an index using a score of 100 to represent the performance of homes based on a reference home built to meet the 2006 International Energy Conservation Code. A net-zero energy HERS home score is 0. The lower a home's HERS score, the more energy efficient it is in comparison to the HERS reference home. Figure 3 is the rating certificate with a score of 17 for the deep-energy demonstration home.

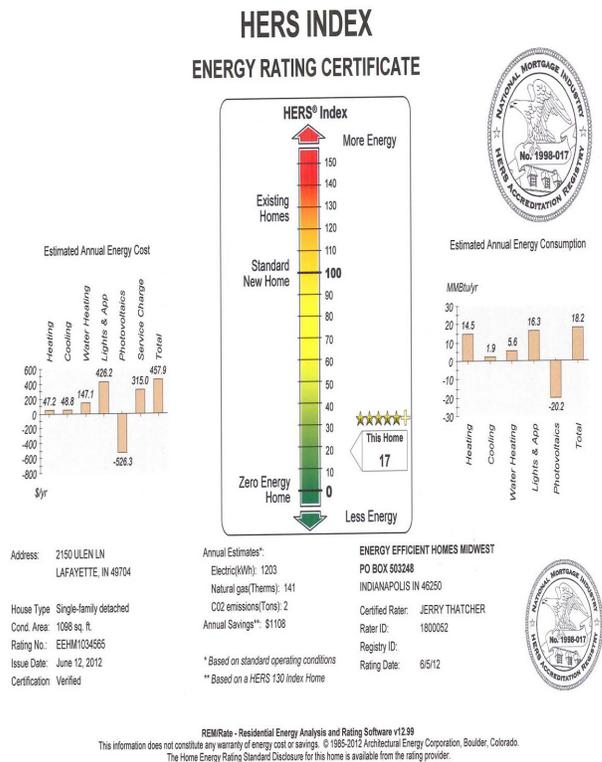


Figure 3. Demonstration Home HERS Rating Certificate

While it is not possible to separate all costs related to the energy-related retrofits from the major modifications to fully rehabilitate the demonstration home, the final energy retrofitting costs were 18% less than the original budget for the deep-energy retrofitting. Some savings came from careful selection and purchasing of ECMs, but the bulk of the savings resulted from the significant reduction of installation costs for solar PV systems that took place between 2009, when the initial budgeting was completed, and the actual installation in 2012. The budget savings allowed three additional grants to be made from program funds for low-income homeowners.

Program Educational Activities

Community outreaches were extensive for the deep-energy retrofit home and retrofit grants. A combination of press coverage, community meetings, open houses, printed handouts, displays, as well as educational seminars for homeowners, contractors, and the academic community were utilized. Press coverage began as soon as the funding award was announced, generating interest almost immediately. This was followed by press releases from the City of Lafayette, Purdue University, and the media group in the College of Technology. Press releases were strategically timed to coincide with phases of the project and opportunities for community interaction throughout the grant period.

The most significant evidence of community interest came during the open house period in the summer of 2012. The deep-energy retrofit home was staffed by students every weekend. Newspaper and radio advertisements, as well as street signage and word of mouth contact throughout the community generated a steady attendance. Weekly attendance ranged from 20 to 35, with visitors coming from the entire Lafayette metropolitan area rather than just the targeted neighborhoods. The consistent attendance prompted the decision to extend the open house period several weeks beyond the original plan.

To extend the outreach penetration, the demonstration home was included in several activities not directly related to LEAP. The first was inclusion as part of the International High Performance Building Conference at Purdue University in July, 2012. This conference included a short course on net-zero homes conducted by the author and several others from the College of Technology and a tour of the demonstration home open to all conference attendees. The researchers who attended the tour included individuals with interest in high-performance buildings, HVAC performance, and compressor design. Several weeks later, the home was included as part of the Parade of Homes conducted each year by the Builders Association of Greater Lafayette.

At each of the open houses and special events, contact information was collected from individuals interested in more in-depth energy-related retrofitting education. Over 40% of the visitors provided contact information. This strong response was an indication of the keen interest the visiting homeowners had in learning more about how they could reduce energy consumption in their homes. To accommodate this interest, a half-day educational seminar was offered for homeowners. Presentations were given on the following content areas by the author and the Ph.D. student involved with supervision of the deep-energy retrofitting.

- Why save energy?
- Energy audit and testing.
- Specific technologies to reduce home energy consumption.
- Renewable energy systems for the home.
- Energy use impact of landscaping, overhangs, site plans.
- What to watch out for when contracting for a home energy retrofitting.
- Choosing appropriate energy-conserving upgrades.
- Energy Monitoring.

The handouts and curriculum developed were used for one additional wintertime open house and homeowner seminar. In the future, these materials will serve as a template for anticipated educational outreach for other programs. An additional half-day educational seminar was offered for contractors and suppliers using topics similar to the homeowner seminar. Greater technical depth was offered and the discussion was oriented to the concerns contracting organizations have as they consider business opportunities in energy-related retrofits. Attendance at this seminar was built through the contacts that the Purdue University Department of Building Construction Management developed by working on a number of projects with the Builders Association of Greater Lafayette.

Discussion

University and student involvement in the project provided benefits to the program outcomes, university community relations, future university research, and student growth. Without the participation of Purdue University, the City of Lafayette would not have initiated a proposal to obtain funds from the DOE retrofitting ramp-up. The resulting grants allowed low-income individuals to reduce monthly costs to help them maintain homeownership in the two foreclosure-prone communities. Purdue University received significant attention in the mass media for their participation, emphasizing positive public relations with the City of Lafayette. Homeowner education provided detailed information for numerous individuals who did not obtain retrofit-

ting grants but were prompted to investigate energy-efficient retrofits for their homes. These benefits to the community will continue to accrue for years to come.

Two graduate students and six undergraduate students were funded by the program to participate in planning, supervision, or community outreach activities. Outreach activities such as these were advocated for the benefit of both the students and society [7]. Undergraduate students acted as tour guides during open house periods at the demonstration home. Because students are frequently overwhelmed by the broad range of options available for energy conservation and topics associated with 'green' design and construction [8], it was necessary that the students learn a great deal about home energy conservation. As is common in service-learning activities, these students recognized their work as a contribution to society [7]. In addition, many improved their skills in public interaction. One graduate student completed his Master of Science thesis on measurements of success in energy use reduction from retrofitting work supported by the homeowner grants. A second graduate student was in the process of completing research on long-term energy use of the homes retrofitted through the grants.

Despite all of the very positive outcomes of the LEAP partnership, not all of the goals of the original retrofitting ramp-up concept were realized. One of the original objectives of the Lafayette program was to reduce the risks that a single construction organization must undertake when it chooses to provide energy retrofitting services for smaller-scale projects. Most small construction organizations choose not to initiate whole-house energy services activities. They typically lack the skills to assess, sell, and complete affordable residential building energy improvements that maximize energy savings for individual homeowners.

The need for market transformation based on contractor competency was emphasized in the conclusions of a 2008 report to the State of Vermont reviewing existing programs in the United States that attempt to eliminate first-cost barriers for energy efficiency improvements in the residential sector. The report by Fuller [9] made six recommendations to the state. The only recommendation not directly related to financing energy-related improvements was to expand the network of energy improvement contractors. The report's author felt that support and action was needed to train more contractors and their crews in a way that would increase the capacity of businesses to serve more customers. They also noted that the programs with the highest volume of energy-related loans had a strong contractor network and included regular communications with the contractor network [9].

Within the Lafayette metropolitan area, the number of contractors qualified to undertake whole-house energy-

related retrofits was very limited. In the two years prior to implementing LEAP, the City of Lafayette had undertaken home renovations which included substantial energy upgrades under the NSP. Only three qualified construction organizations responded to the call for bids, even though during this period an economic recession limited participation in other construction activity. LEAP initially intended to attract small-scale residential renovation contractors who would like to expand into energy services contracting. The potential for up to 80 government-funded home retrofits in two contiguous communities provided strong market potential. If successful, at the end of the three-year program, a qualified group of whole-house energy services contractors would be operating in the Lafayette metropolitan area.

Subsequent to the final funding document preparation for the Lafayette award, the DOE administrators released guidance about applicability of the Davis Bacon wage rules for retrofitting activities. Davis Bacon is a series of related acts of the U.S. Congress administered by the U.S. Department of Labor (DOL), which require all contractors and subcontractors performing work on federally funded contracts in excess of \$2,000 to pay wages and fringe benefits equal to or greater than the prevailing wages in the area of the project [10]. In some geographic areas, the prevailing rates were established wage rates paid to unionized labor. For small residential projects, the prevailing wage rates may not be heavily influenced by union negotiations. Nevertheless, the current Davis Bacon rules require substantial record-keeping and reporting. These reporting requirements typically prevent small contractors from participation in federally funded work. As a result, all LEAP retrofitting work for homeowners receiving grants was completed under the management of a large general contractor. This conflict of priorities constrained the growth of a viable small contractor base for energy retrofits. Market transformation through growth of a qualified group of whole-house energy services contractors in the Lafayette market did not take place.

Conclusion

This case study introduces one approach to the worldwide residential energy use challenge presented by the large number of individually owned and operated homes that were constructed when the energy consumed to operate these structures was not a consideration in design and construction. By combining multiple government programs, cosmetic and lifestyle upgrades were completed along with energy efficiency upgrades. This showcase for a whole-house view of refurbishment services, where savings in cost and complexity can result from completion of energy-conserving measures while completing other housing re-

pairs or cosmetic upgrades, is an example for both subsidized and market-rate retrofits.

The author's experiences with this case demonstrate the need for program managers to understand the complexity of energy-related retrofits. The case also demonstrated that quality control is a major challenge to successful energy retrofitting programs. Over the upcoming years, both the demonstration home and the subsidized retrofit homes will be monitored to confirm the actual energy reduction benefits of the program.

Major benefits accrued for the Glen Acres and Vinton Communities, but questions remain about how well the program achieved the originally intended goals. No market transformation took place to increase the supply of contractors pursuing energy services work. Contractor knowledge was improved somewhat, but for the city overall a skills gap persists. In the U.S., natural gas prices are falling, which offers little financial incentive for energy-conserving retrofits. Homeowners continue to show a personal preference for visible upgrades. In addition, financing and valuation norms support visible upgrades, while at the same time ignoring energy-related upgrades. Contractors have no compelling reason to close the skills gap and sell energy-related upgrades unless government programs finance the work and promote the energy-related investment. In this case, conflicting priorities from government wage rate support essentially nullified any incentives for contractors to participate.

Thirteen jobs were created by the program in the most recent quarterly report for the DOE grant [11], but job creation reporting was not required by small sub-recipients of funding such as the City of Lafayette. As a result, it was not clear if any Indianapolis or Lafayette jobs were included in the report. Job growth was probably negatively impacted by the Davis Bacon wage rate recordkeeping and reporting requirements as well. These observations serve to demonstrate the potential for failure when competing regulatory interests are not considered in program design. The sharing of additional case study experiences as new energy-conserving programs are developed and put into action is encouraged so that others can learn from the experiences and outcomes of each new program. Above all, future programs need greater engagement of small contractors typically employed for residential retrofitting in program activities. Engaging students in similar programs as part of their normal coursework is also advisable.

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Biography

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BUILT TO FAIL? A LITERATURE REVIEW OF R&D ORGANIZATION PERFORMANCE MEASUREMENT SYSTEM ASSESSMENT

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Abstract

When designed appropriately, performance measures are used to inform decision making, assess and improve business processes, and provide a quantitative perspective for an organization's strategic vision. However, performance measurement system (PMS) implementations often fail as a result of unbalanced and inappropriate metrics, resulting in significant organizational cost and wasted opportunities. This is especially true in R&D systems, where time horizons are extended and poor performance measures can result in years of lost time and millions of dollars in wasted organizational investments. But why do so many performance measurement systems fail? In this paper, the authors attempt to answer this question by discussing current performance measurement systems, PMS assessment frameworks, and R&D performance measurement. Finally, a systems-based approach will be proposed as a means to improve the effectiveness of the PMS implementation assessment.

Introduction

Organizations utilize performance measures and performance measurement systems (PMSs) to inform decision making and to assess and improve their business processes [1]. When well designed, they can effectively support an organization's mission and strategy [-4] and help produce the desired outcomes associated with R&D engineering and technological development. When properly implemented, they help organizations maintain a clear trajectory while developing new R&D technologies. However, if the wrong measures are selected, not properly balanced, not tailored to the company's objectives, or fail to fit the proper context of the organization, then the investment in an organization's performance measurement system is likely to be wasted on a failed system [3-5].

We are bombarded everyday with political approval ratings, earnings reports, stock prices, sports statistics, and even vote tallies for the best singers on American Idol. The idea of measuring performance is ingrained in our psyche. Yet somehow, when it comes to measuring R&D technical performance, organizations often seem lost trying to figure

out how to apply metrics to non-financial business functions, dealing with time-lags associated with R&D, finding norms for comparison, and getting "buy in" from individuals within the organization [5]. R&D organizations are left to ponder, how useful is my PMS in helping me to meet my organizational goals and objectives? Further, how can I assess my PMS and its efficacy? To answer these questions, the authors review here the current state-of-the-art performance measures and PMSs, and PMS implementation assessment. A systems-based approach is then suggested as a means for improving the effectiveness of PMS implementation assessment in further research.

An Overview of Performance Measurement

It is now widely accepted that performance measures cannot be built from a single, backwards-looking accounting perspective [6-8], but instead must be built from a holistic perspective with an understanding of the measurements' purposes, stakeholder perspectives, organizational mission, and system context [1], [3], [5], [9]. PMS designs for R&D must integrate metric requirements with a capable information technology (IT) system to create viable data collection and feedback systems [10]. Without the ability to keep up with the data that is being collected and act on it, organizations may find that they are just counting. This concept is relevant for R&D in multiple technological disciplines including engineering, healthcare technology, and university programs [11]. But why should an organization invest in performance measurement?

Behn [9] proposes a set of eight purposes that public managers have for measuring performance: evaluate, control, budget, motivate, promote, celebrate, learn, and improve. He points out that "the public manager's real purpose – indeed, the only real purpose – is to improve performance. The other seven purposes are simply a means for achieving this ultimate purpose". Other authors have recognized further benefits that organizations may expect, including:

1. Improving stakeholder confidence by providing accountability [10], [12], [13].

2. Increasing transparency [10].
3. Providing defined goals and scopes for projects, allowing for more concrete design, planning, and implementation [14].
4. Providing very specific success criteria for projects [14].
5. Having the psychological value of reducing anxiety in the face of uncertainty by providing the assumption of control and predictability [14].
6. Increasing efficiency and productivity [15].
7. Defining what constitutes “effectiveness” [16].
8. Providing data for decision making [5].
9. Allowing outcomes to be assessed at the end of implementation [14].
10. Meeting stakeholder expectations [11].

The benefit of meeting stakeholder expectations plays a central role in technological engineering and its fundamental ties to R&D. For example, Fuhne [11] notes that measuring performance is a requirement for ABET engineering technology accreditation. Further, the United States National Laboratories are required, by contract, to report on a set of measures provided by the Department of Energy. The performance information is then assessed and benchmarked. These identified benefits provide tangible reasons for organizations to purposefully measure performance.

However, picking the wrong measures, not balancing measures across different perspectives, or failing to consider a system’s context holistically can result in the process of measuring performance being meaningless [3-5], or even counter-productive. Papparone and Crupi [14] provide a number of downfalls that can be associated with misguided implementation and/or analysis of performance measurement, as shown in Table .

So, while measuring performance is necessary, there can be negative consequences associated with the improper development and interpretation of performance measures. Developing performance measures to fit the unique context of an organization is necessary if one hopes to create a PMS that takes advantage of the benefits of performance measurement while managing to avoid potential pitfalls. Nowhere is this truer than in R&D organizations.

Why R&D Measurement is Unique

Many of today’s companies have determined that R&D is a requirement for maintaining a long-term competitive advantage [17]. In the past, R&D was thought of as an unstructured and artistic process that would be inhibited in a

system that attempted to control its performance [18]. Today, modern business processes expect that R&D must be accountable to its parent business in terms of efficiency, effectiveness, and strategic alignment with customer needs and the overall organizational mission [19]. R&D operations cannot be considered as independent and isolated activities but instead must be seen as a critical component of a company’s strategic vision [18], [20]. However, a universally accepted set of R&D measures still does not exist [1]. So, what it is that makes R&D measurement unique?

Table 1. Possible Shortfalls Associated with the Implementation of Performance Measurement (Adapted from the work by Papparone and Crupi [14])

| | |
|---|---|
| 1 | Unconsciously adopting a paralysis-by-analysis mentality at the expense of a learn-by-doing mentality |
| 2 | Confusing quantitative knowledge with the quality of wisdom |
| 3 | Making linear assumptions of causality vice appreciating the complex, interactive, dynamic patterns of causality. |
| 4 | Jumping to implementation of solutions without taking time to understand an ever-changing problem as a continuous process. |
| 5 | Assuming that by breaking down the system into measurable segments or by deconstructing the processes within, the sum of the parts will equal a measure of the whole. |
| 6 | Failing to consider other process options because one has selected measures for the process in use. |
| 7 | Reinforcing one's cultural penchant for low-cost and high-speed measuring versus appreciating the richness and quality of observing and experiencing the actual activities in progress. |

Several authors point out differences that exist between performance measures in R&D and those found in production and manufacturing environments. One example is time lag. Automotive manufacturers may wait two years between R&D work and first product sales, while lag times for Bell Labs basic research projects are typically between 7 and 19 years [5]. This creates a need for measures that differ from those in manufacturing and production environments. Measuring short-term indicators such as the number of products sold, return on investment, or cycle time is not meaningful in an R&D context. Appropriate measures must instead be developed for an R&D context [1], [2], [6], [7], [9], [21], [22].

Issues inherent to R&D lead to additional complexity in the implementation of a PMS. Szakonyi [23] notes that when measures are put in place to measure R&D outputs,

they tend to focus on quantitative outputs such as the number of patents or published papers. These indicators may help show that work is being done, but they do little to evaluate the true R&D outcomes which give an indication of the organization's long-term effectiveness or profitability. These aspects of R&D have made performance in the field extremely difficult to measure and control [1], [5] and have led to a lack of any widely accepted set of R&D performance measures [1], [23].

Financial indicators are also used to evaluate R&D. For example, technology and engineering organizations, such as the national labs and NASA, often use time and cost to evaluate the success of R&D project goals. However, this strategy can lead to a short-term focus that doesn't support the organization's long-term strategy [13], [23-25]. While financial indicators may help to provide some insight into the R&D contribution to an organization's output, these measures simply cannot adequately address the quality or appropriateness of the R&D contribution with respect to an organization's mission and strategy [23, and thus, its outcomes.

There is broad agreement in the literature that an effective PMS for R&D must be tailored to the system context [1], [2], [7], [9], [21-23], [25]. For example, Kaplan [7] notes that the value of an investment banker at Goldman Sachs may be in his or her ability to have both an expertise in financial products and maintaining relationships with valuable clients, although the value of this same employee may be totally different in the context of an online investment company like etrade.com. This holds true in the R&D context. If an R&D system struggles to have people with the right skills in place for a new R&D initiative, or employees don't understand how to develop practical ideas in the context of the organization's mission, funding, and allotted timeframe, then the effectiveness of the R&D system will suffer [23]. R&D organizations need to consider and address the unique challenges of effectively staffing employees appropriate to their specific system. These issues make the implementation of a PMS framework in R&D contextually complicated. To address these issues, several authors have provided guidance to help with R&D performance measurement success. The following section details several well-known PMS frameworks and how the literature suggests they could be tailored to an R&D context.

Performance Measurement Systems and R&D

Arguably the most well-known PMS framework is the Balanced Scorecard [26]. The Balanced Scorecard stresses

causal linkages between four perspectives—financial, internal, customer, and learning—which are built to support an organization's vision and strategy [26]. Kerssens-van Drongelen and Cook [5] have adapted the Balanced Scorecard so that it can be implemented in an R&D environment. For example, they note that the financial perspective can be derived from other perspectives in the Balanced Scorecard: internal business, and innovation and learning. From these measures, higher-level management could make informed decisions concerning allocation of resources, career development, and reward structures [18]. The authors state that measurement system design is primarily determined by “the purpose of the measurement and the objectives formulated for the subject of the measurement”. They then identify five additional areas that affect measurement system design which they call contingency factors. These factors are: 1) organizational level, 2) type of R&D, 3) type of industry, 4) organizational size, and 5) strategic control model. These factors are used to tailor the R&D measurement system, including measures and procedures.

Although not specific to R&D, several other frameworks have been developed to guide the development of performance measures in organizations. The Performance Prism [22] was introduced as a measurement framework that would address measurement from a different perspective than previous PMSs. The authors contend that other PMSs, such as the Balanced Scorecard, are centered primarily on strategies, and they argue that designing performance measures around strategy has led to organizations failing to fully consider what they are truly hoping to accomplish: satisfied stakeholders. The Performance Prism includes five facets—stakeholder satisfaction, strategies, processes, capabilities, and stakeholder contribution—based on stakeholder perspectives [22]. By understanding and addressing the stakeholder's needs, a company can create an effective PMS capable of supporting the long-term success of the organization. Questioning the basis for an organization's strategy, with respect to stakeholder perspectives prior to selecting measures, is a strength of the Performance Prism [27].

The Performance Measurement Matrix [28], like the Balanced Scorecard, links different dimensions of performance including financial and non-financial costs and internal and external focus. The Results and Determinants framework [29] ties results to competitive performance and financial performance, while tying determinants to quality of service, flexibility, resource utilization, and innovation. By doing this, the framework highlights the determinants as leading indicators of future results [3]. The Performance Pyramid [30] is a hierarchical four-level pyramid which links strategic objectives from the top down, while linking performance measures in a bottom-up manner [1]. It also identi-

fies linkages of both internal and external performance measures. Although these frameworks have their differences, they all provide guidance that their authors assert will lead to improved performance. With all the guidance that can be found in the literature for PMS development and implementation, one is left to question: Why do so many PMS implementations fail?

Why Performance Measurement System Implementations Fail

Implementations of PMSs, such as the Balanced Scorecard, are often unsuccessful [31], [32]. One reason for failure is that organizations often blindly follow PMS design perspectives and allow the PMS framework to constrain the implementation [33], leading to “excessive, redundant or flawed measures that drive inappropriate behaviours”. The usefulness of the PMS implementation is dependent on the person or team correctly understanding and interpreting the intentions of the PMS framework as well as their skill at developing the right measures. For example, Kerssens-van Drongelen and Bilderbeck [18] evaluated nine companies and found that, while most of the R&D measures they used in practice could be categorized within the framework of the Balanced Scorecard, the measures were not balanced for the four perspectives at the individual or company level. Creating a useful PMS is a difficult endeavor requiring technical expertise which may not always be available [10]. Lack of proper skill, knowledge, or assistance can lead to a flawed PMS implementation, and, while there has been significant work by practitioners to refine the way in which effective PMSs are built, significantly less guidance can be found on rating the effectiveness of PMS implementations [8]. This presents significant implementation issues.

Scholarly literature [31] suggests that as many as 70% of PMSs fail as a result of their implementations. Further, Wall and Counet [32] surveyed performance management experts and found that they believe an average of 56% of PMS implementations fail specifically because of implementation problems. This general agreement between scholars and practitioners concerning the failure rate of PMS implementations leads one to question the reasons for the failures.

It has been suggested that PMS implementation failures can generally be placed into three categories: context, process, and content [8]. The first category, context, is concerned with how an implementation will be affected in its environment. Earlier work by Neely and Bourne [31] also detailed three categories associated with PMS failures: political, infrastructural, and focus, which may be considered

as sub-categories of context. The second failure category identified is process. Process is concerned with the robustness of the PMS with regards to how well an implementation meets the intentions of the PMS framework design. The third category, content, refers to the measurements themselves and how well they meet the intentions and needs of the system. Table 2 details specific failure causes associated with each category.

Table 2. Main Reasons for Performance Measurement Implementation Failures [8]

| PMS Failures | | |
|--|---|---|
| Context | Process | Content |
| The need for a highly developed information system | Vision and strategy were not actionable as there were difficulties in evaluating the relative importance of measures and the problems of identifying true "drivers" | Strategy was not linked to department, team and individual goals |
| Time and expense required | Strategy was not linked to resource allocation | Large number of measures diluted the overall impact |
| Lack of leadership and resistance to change | Goals were negotiated rather than based on stakeholder requirements | Metrics were too poorly defined |
| | State of the art improvement methods were not used | The need to quantify results in areas that are more qualitative in nature |
| | Striving for perfection undermined success | |

These failure causes align with Wall and Counet [32], who completed a factor analysis on the results of a combined literature review and expert feedback study. The results identified the following PMS implementation problems [32]:

1. There is insufficient commitment from middle management and staff for PMS implementation.
2. There is resistance from organizational members towards the new PMS.
3. Management puts low priority on the PMS implementation.

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4. The system lacks cause-and-effect relationships or is overly complex due to too many causal relationships.
 5. The current information and communication technology system does not support the PMS adequately.
 6. There are insufficient resources and capacity available for the implementation.
 7. There is a lack of knowledge and skills in regards to the PMS.
 8. The PMS is not used for the daily management of the organization.

This problem list also aligns well with the context category identified earlier. These findings point to a fundamental issue associated with PMS frameworks: While PMS frameworks can provide a solid base for both process and content, the context in which the PMS resides must be properly understood and accounted for during implementation, as well as during the PMS's lifecycle, in order to provide a foundation for success.

Over-reliance on quantitative measurement can also present a problem in a PMS implementation [33]. Several drawbacks exist, many associated with the R&D environment, that point to a need for balancing qualitative measures in many situations. This is an issue associated with the content PMS failure mode. Organizations that rely too heavily on quantitative measures may be missing a part of the bigger picture that can be more readily seen through a qualitative lens. Brown and Gobeli [34] list some of the pitfalls associated with quantitative measures including:

- They don't work well in professional groups, such as in R&D organizations, where much of the work is characterized by uncertainty and variability, and the outputs are relatively intangible.
- They don't work well where projects and products are customized, as is the case in many high-tech, contract research situations.
- They don't allow for important subjective perceptions of much professional work, as when sales of a complex, technical product are heavily dependent on customer perceptions of the ease and availability of product maintenance and repair.
- They don't adequately measure the long-term outcome of an emerging technology or a new product's development, i.e., the strategic importance of such developments to broader corporate goals.
- They generally leave out social factors, and thus provide little help to managers in evaluating leadership styles, communication patterns, etc.

In short, many of the pitfalls that Brown and Gobeli [34] discuss show that a purely quantitative approach to performance measurement within an R&D enterprise is a recipe

for disaster. Another problem associated with PMS implementation is a lack of effective feedback. Neely and Bourne [31] identify a fundamental feedback problem associated with many PMSs: failure of the organization to actually use measurement information. If an organization has not implemented a system that uses the performance measurement data to improve itself, then how can the PMS truly be valuable? The changes that drive improvement must come from the analysis of the performance measures, and decisions must be made to affect improvement over time.

These cited issues provide the foundation for understanding why PMS implementations often fail. If organizations use quantitative measures where a qualitative understanding is required, or if a measurement system is not built from the organization's mission, or if the environment that the PMS is being developed for is not well understood, then the PMS implementation has a higher chance of failure. However, it cannot be assumed that organizations that implement a PMS simply ignore these issues. The high failure rate of implementations supports the belief that many of these issues are not easily identified during the implementation phase, nor are the issues corrected after implementation. An assessment framework that allows a company to assess its PMS implementation as a system and utilize the information to make corrections to its PMS could provide a means for improving it.

Existing PMS Implementation Assessment Frameworks

While there are numerous papers on PMS development and implementation, significantly less information appears in the literature with respect to assessment of PMS implementations. The optimal PMS for organizations will vary from case to case [27] and in different settings [31], which means a pre-determined set of metrics cannot be used for different implementations. There is a need for a structured methodology available for practitioners to assess their PMS implementation [35]. The literature proposes a number of assessment frameworks to address the issue. Several of the existing PMS implementation assessment frameworks found in the literature are listed with their descriptions in Table 3. Although these frameworks provide a basis for assessment of PMS implementation, as previously stated, the failure rate of PMSs remains above 50% [32], making it clear that a new approach is warranted. At the time of this writing, no work explicitly dedicated to a systems-based approach to PMS implementation assessment for R&D systems has been found. Using a structured systems approach may help to identify issues associated with understanding systems that reside in complex organizational environments.

Table 3. PMS Implementation Assessment Frameworks

| PMS Assessment Framework | Description |
|--|---|
| Performance measurement questionnaire [36] | Utilizes a questionnaire to rate importance and emphasis of and organization's metrics to align the organizations performance measures with strategy and determine the extent to which the performance measures support the strategies. Identifies "gaps" (areas where new measures are required) and "false alarms" (unneeded measures). |
| Performance measurement grid and checklist [35] | Utilizes a six stage process to identify un-used measures and gaps. Extends the Performance measurement questionnaire. Incorporates a feedback loop in process and was built using practitioner feedback. |
| PMS System Class Ranking Systems [27] | Uses a three class system to assess the PMS: First (mostly financial - least mature), Second Class (balanced), Third Class (fully integrated - most mature). |
| Integrated performance measurement system (IPMS) [37] | Suggests a framework and IT platform are required to assess the dynamic agility of an organizations PMS. |
| Improvement System Assessment Tool [38] | Rates maturity and effectiveness of a PMS using four scoring dimensions: approach, deployment, study, and refinement. |
| The Four Stage PMS Maturity Model [39] | Rates maturity of multiple assessment areas. |
| Small and Medium Size Enterprise PMS Assessment [2] | Develops a maturity grid for PMS assessment based on literature derived best practices. |
| Structured Framework for the Review of Business Performance [40] | Reviews business and PMS performance based on the PMS design process characteristics. |

Improving Assessment through the Systems Approach

Systems theory, along with its associated approach and principles, is useful when studying complex, socio-technical systems [41] including the technologically complex systems associated with R&D. PMSs are built to provide guidance for complex systems that involve managers, processes, customers, suppliers, shareholders, stakeholders, policies, politics, and the environment. This is to say that they operate in a real-world system.

Systems theory offers a means by which to address complex organizational issues [42] such as those found in PMS implementations. Complex systems cannot adequately be understood by looking at the individual pieces of the system. The behavior of the total entity is more than can be understood by determining the behavior of its individual elements [43], [44]. The systems approach deals with complex systems as entities in their totality rather than as the sum of their parts [21]. It demands a mode of systems think-

ing that is based on understanding the characteristics of human activity systems, holistically, with regards to emergence, hierarchy, communication, and control [44].

As discussed previously, flaws can be present in PMS implementations such as a narrow set of metrics, short-term goals, or backwards-looking accounting-based measures [3], [6], [26]. Problem areas will inevitably emerge from flaws such as these and a systems approach can yield insight into the way a system's hierarchy, communication, and control mechanisms can affect, for better or for worse, these emergent issues. PMS implementation problems can and should be expected in R&D organizations. The systems approach avoids reductionism and looks at problems within the context of the larger human activity systems [45], such as the system performance measures that are implemented within. Systems thinking can identify problem areas that often occur when managers are looking to oversimplify or when they believe that they can disregard existing social aspects within a system's environment.

The systems approach takes system relationships, interactions, and integration into consideration [41]. As

such, there are strengths and weaknesses associated with the approach, as discussed by Hester et al. [46]:

The strengths of a systems methodology include systemic structure of thinking, design, and execution; explicit logic and rationale in approach; implicit logic of systems philosophy; accepted, understood, and proven approaches to the design and analysis of system problems or situations; and language and philosophy of holistic inquiry. Conversely, the limitations of a systems methodology include additional layers of complexity, including consideration of compatibility with context, infrastructure, values, and worldview; determination and alignment of approach, decision, action, and interpretation, outputs and outcomes, and compatibility; and systems expertise and maturity. (p. 575)

Although the systems approach adds complexity to the way a problem situation must be dealt with, it is essential for creating a complex, functional understanding of the implementation of PMSs in organizational settings. It can be used to build a methodological approach that considers organizational elements such as products, processes, resource allocation, learning, vision, and social issues. It can also identify issues with the investment of organizational leadership, involvement of key managers, supervisors, and technicians, as well as participation of relevant stakeholders [10].

These are all critical for the establishment of an effective PMS.

The authors of this current study assert that an assessment framework for PMS implementations could be developed by utilizing a systems-based approach to inform, guide, and structure the developmental process. Adams et al. [47] propose a formal definition and construct of system theory which is built from the unification of specific propositions and principles. It was derived from over 40 individual fields of science into an axiom set. The construct defines a way for real-world systems to be evaluated so that one can seek to gain a more complete understanding of them. Seven axioms, together with their supporting principles, provide the formalized basis for dealing with complex systems.

These axioms provide the lens through which one can look at a system, including organizational systems and their associated issues and behaviors as they occur in the real world. A systems methodology will be informed by this systems theory as described in these axioms. It can be used to build a methodology that can deal with organizational elements such as products, processes, resource allocation, learning, vision, social issues, the investment of organizational leadership, involvement of key managers, supervisors, and technicians, as well as participation of relevant stakeholders [10], [48], which are all critical for the establishment of an effective performance measurement system.

Table 4. Axioms of System Theory [47]

| Axiom | Explanation | Proposition and Primary Proponent |
|-------------|--|--|
| Centrality | <i>central to all systems are two pairs of propositions; emergence and hierarchy, and communication and control.</i> | Communication, Control, Emergence, Hierarchy |
| Contextual | <i>system meaning is informed by the circumstances and factors that surround the system.</i> The contextual axiom's principles are those which give meaning to the system by providing guidance that enable an investigator to understand the set of external circumstances or factors that enable or constrain a particular system. | Complementarity, Darkness, Holism |
| Design | <i>system design is a purposeful imbalance of resources and relationships.</i> The design principles provide guidance on how a system is planned, instantiated, and evolved in a purposive manner. | Minimum Critical Specification, Pareto, Requisite Parsimony, Requisite Saliency |
| Goal | <i>systems achieve specific goals through purposeful behavior using pathways and means.</i> The goal axiom's principles address the pathways and means for implementing systems that are capable of achieving a specific purpose. | Equifinality, Multifinality, Purposive Behavior, Satisficing, Viability |
| Information | <i>systems create, possess, transfer, and modify information.</i> The information principles provide understanding of how information affects systems. | Redundancy of Potential Command, Information Redundancy |
| Operational | <i>systems must be addressed in situ, where the system is exhibiting purposeful behavior.</i> The operational principles provide guidance to those that must address the system in situ, where the system is functioning to produce behavior and performance. | Dynamic equilibrium, Homeorhesis, Homeostasis, Redundancy, Relaxation Time, Self-organization, Suboptimization |
| Viability | <i>key parameters in a system must be controlled to ensure continued existence.</i> The viability principles address how to design a system so that changes in the operational environment may be detected and affected to ensure continued existence. | Circular causality, Feedback, Recursion, Requisite Hierarchy, Requisite Variety |

Conclusion

In this study, the authors explored literature in four areas: performance measurement in R&D, PMSs, performance measurement assessment and systems, to better understand the issues surrounding PMS implementation assessment in R&D. PMS frameworks such as the Balanced Scorecard [26] and Performance Prism [22] were built to guide organizations in designing measurement systems, but often stop short of providing the guidance that is necessary to identify, establish, and use the measures to reach the organizations' desired goals [3]. Aspects of R&D have made performance measurement in the field extremely difficult to measure and control [1], [5] and have led to a preclusion of any widely accepted set of R&D performance measures [1], [23]. While some literature exists on PMS assessment, the area of study seems to be in its embryonic stage and the authors found no studies dedicated expressly to R&D PMS implementation assessment. Further, while many PMS frameworks give consideration to systems theoretic perspectives, the PMS assessment frameworks are not expressly built from a structured systems-based methodological approach. The noted failure rate of PMS implementations strongly suggests a need for further research. A systems approach to PMS implementation assessment has been suggested as a method to fill this need by offering a way to address the complexities associated with PMS implementations in their organizational contexts.

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AN APPROACH TO INCORPORATING SUSTAINABILITY IN A MANUFACTURING ENGINEERING TECHNOLOGY PROGRAM

Rex C. Kanu, Ball State University; Pamela E. Betz, Ball State University; Samuel Cotton, Ball State University

Abstract

There seems to be a strong perception in many parts of the world that global economic activities are not sustainable, given the rate of consumption of non-renewable natural resources such as fossil fuels. For example, since land-based petroleum findings or wells are being depleted, there is an increasing need to explore the deep seas for petroleum. Similarly, the mining of metal ores is becoming increasingly difficult, as many of the easily accessible mines are being depleted. Given this scenario, there is a push from environmentalists, industrialists, and concerned citizens to promote sustainability. However, not everyone agrees on the definition of sustainability. Sustainability is defined as “the development that meets the needs of the present without compromising the ability of the future generations to meet their own need [1].”

In the Manufacturing Engineering Technology program in a Midwestern university, aspects of sustainability are incorporated into some courses at the freshman, sophomore, and junior levels. The pedagogical tools used to introduce students to sustainability in these courses include presentations, class discussions, homework assignments, and projects. With regard to projects, some students in a junior-level plastics course chose to work with a biopolymer, polylactic acid (PLA) and clay nanoparticles to make polymer-clay nanocomposites. PLA is a renewable and environmentally friendly raw material. Clay nanoparticles are naturally occurring materials that are environmentally and ecologically safe. A goal of this project was to introduce the students to the concept of sustainability by researching and working with renewable materials such as PLA and clay nanoparticles in a hands-on laboratory setting. The mechanical and flame-retardant properties of the polymer-clay composite were compared with the control, virgin PLA specimens. The results of the project were shared with the entire class via a presentation.

The students’ understanding of sustainability was assessed in the course’s examination, and the results of the assessment were shared in a paper presentation at the 2012 conference. It was anticipated that the findings of this study

would be useful to those seeking to introduce their students to sustainability and sustainable development.

Introduction

In *The Prize*, Yergin [2] claims that the global oil industry began with the first commercial oil well drilled in Titusville, Pennsylvania, USA, in 1859; and by 1901 it was claimed that Pennsylvania oil fields produced more than 50 percent of the world’s oil supply [3]. Fast forward to 2012, the oil industry in Pennsylvania is, for all practical purposes, non-existent because its wells have been depleted to levels that are no longer technically and economically viable for oil extraction. The wells affected the region economically, socially, and environmentally. The then-booming Pennsylvania oil industry provided employment to its indigenes, attracted skilled labor from other regions and cultures, and increased the value of local properties (cost of farmland, rentals, and home prices); however, it also made some farmlands useless for farming because of soil contamination caused by oil spillage. One may ask, “What does the history of the oil industry in Pennsylvania have to do with sustainability?” To answer that question, it is important to define the term sustainability.

According to the most widely quoted definition of sustainability and sustainable development, which is the definition of the Brundtland Commission of the United Nations on March 20, 1987: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [4].” While this definition applies to all fields of endeavor, Allwood [5] suggests that with regard to manufacturing, sustainability or sustainable development is the ability to develop technologies to transform materials without emission of greenhouse gases, use of non-renewable or toxic materials or generation of waste. Although Allwood’s definition of sustainability is somewhat more restrictive than the Brundtland Commission’s definition, it sets an ultimate goal for sustainable manufacturing. It is restrictive in the sense that very few manufacturing processes occur without some form of waste, no matter how efficient the process may be.

Since the need for sustainability is rather obvious, given events like the demise of the Pennsylvania oil industry, how can we promote sustainable practices in our daily activities? Cognizant of this need, Kofi Annan, General-Secretary of the United Nations, in 2001 remarked that “Our biggest challenge in this new century is to take an idea that seems abstract—sustainable development—and turn it into a reality for the entire world’s people.” [6] The United Nations Decade of Education for Sustainable Development 2005-2014 [6] proposed “reorienting educational programs by rethinking and revising education from nursery school through university to include a clear focus on the development of knowledge, skills, perspectives, and values related to sustainability that is important to current and future societies” as a means of meeting this challenge. Also, a review of the literature indicates that there is a growing body of work proposing the integration of sustainability into higher education [7-11].

In this paper, the authors describe ongoing attempts in a Midwestern university to incorporate sustainability into its bachelor’s degree program in manufacturing engineering technology (MET). Presently, the MET program does not have a course dedicated to teaching sustainability. Hence, the adopted approach was to introduce sustainability as components of some MET courses taught at the freshman, sophomore, and junior levels. These courses include Technical Design Graphics, Manufacturing Materials, and Plastics. None of these components includes Life Cycle Analysis of a product. It was anticipated that lifecycle analysis tools such as the Okala Life Cycle Analysis Calculator would be used in assessing sustainability of manufactured products in the fall, 2012, and spring, 2013, semesters.

Methodology

In these classes, the impact of human activities on the environment was used to initiate discussions about sustainability and sustainable development. To aid the discussions, slides of Figures 1-6 were shown to the students.

Following the discussions on sustainability, students were assigned projects that would integrate particular course content with the concepts of sustainability. Examples of these projects are described in subsequent sections of this paper.

Technical Design Graphics: A Freshman-Level Course

The course description states that it is an “introduction to mechanical design and production drawing. Topics covered in the course include sketching, solid modeling, multiview

drawings, auxiliary and section views, dimensioning and tolerancing, and the creation of working drawings.” As noted earlier, the goal of the project was to integrate skills acquired in the course with the principles of sustainability in order to develop a new product or modify an existing product. Figure 7 shows a concept pencil sharpener that utilizes used beverage bottles to collect the pencil savings. Figures 8 and 9 show the components of the pencil sharpener, while Figure 10 shows an assembly of the components. The designed part was manufactured with a Fused Deposition Machine (FDM) rapid prototyping machine – uPrint™ by Dimension®. The sustainability principle employed in this project was the reduction of material resources by recycling used beverage bottles. This product was designed and built by student Charles Russell.



Figure 1. Deforestation in Atlantic Forest Rio de Janeiro, Brazil (This hill was deforested in order to use its clay in civil construction in Barra da Tijuca) [12]



Figure 2. Plastic Waste [13]

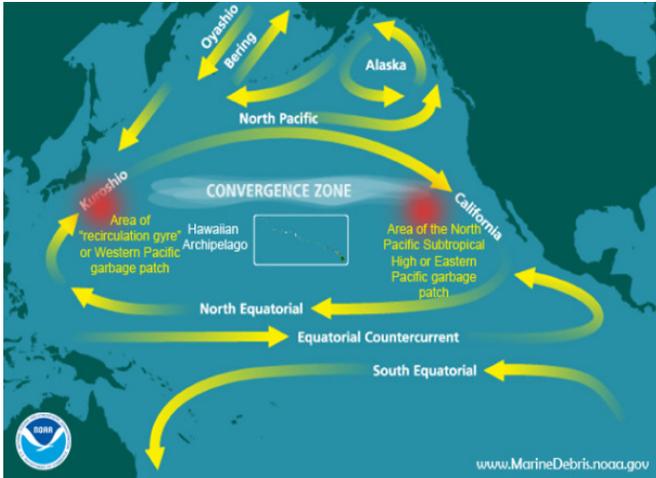


Figure 3. An Ocean Filled with Our Plastic Waste that Exceeds the Size of the State of Texas, USA (According to one sailor) [14]



Figure 6. Oil Spills have Fouled Drinking Water in the Niger Delta (A man in Ogoniland, Nigeria) [16]



Figure 4. The Tilden Open-Pit Iron Ore Mine in Michigan, USA (1930) [15]



Figure 5. The Tilden Open-Pit Iron Ore Mine in Michigan, USA (Present condition, but it has been suggested that the bottom of the mine will soon become the lowest point in the State of Michigan) [15]



Figure 7. Pencil Sharpener and Bottle Assembly

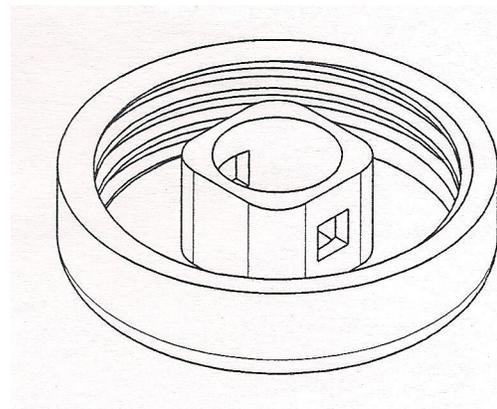


Figure 8. Cap Component of Assembly

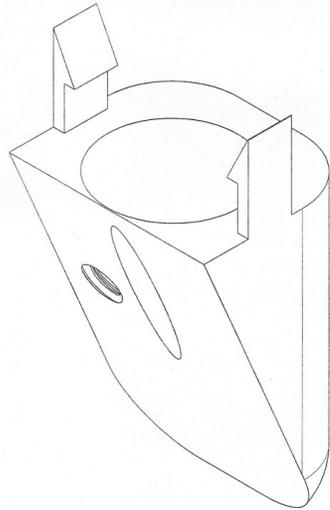


Figure 9. Sharpener Component

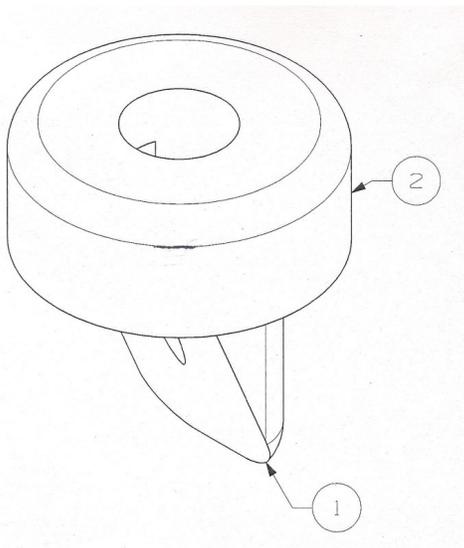


Figure 10. Sharpener Assembly Consisting of the Sharpener (1) and the Cap (2)

Manufacturing Materials: A Sophomore-Level Course

The course description stresses the “fundamentals of materials science with an emphasis on how material properties influence their application in products and processing. Metallic, polymeric, and ceramic materials will be discussed.” A principle of sustainability explored in this course is the impact of materials usage on the environment. Student projects primarily focused on materials selection using Granta’s CES Edupack software that complements the material’s

textbook by Ashby et al. [17]. CES Edupack has a database for estimating the carbon dioxide (CO₂) footprint of many materials based on their primary and secondary production processes. Thus, the CO₂ footprint of materials can be used as a criterion for selecting appropriate materials for specific applications. Examples of student projects taken from Ashby et al. [17] are described here. The projects shown here were parts of several projects completed by Karl Rauchenstein.

Project 1: Materials for Knife Edges and Pivots

Precision instruments like clocks, watches, gyroscopes, and scientific equipment often contain moving parts located by knife-edges or pivots. The accuracy of location is limited by the deformation of the knife-edges, or pivot, and the mating surface. Choosing materials with high Young’s modulus minimizes elastic deformation; plastic deformation is limited by choosing materials with high hardness. Figure 11 shows an example of the use of a knife-edge pivot in a moment weight scale. The strain gauge load cell measures the moment of weight in the hanging pan about the knife-edge pivot.

Requirements:

Young’s modulus: as large as possible.

Hardness: as large as possible.

Select two or three of the best materials and rank them by their ECO properties.

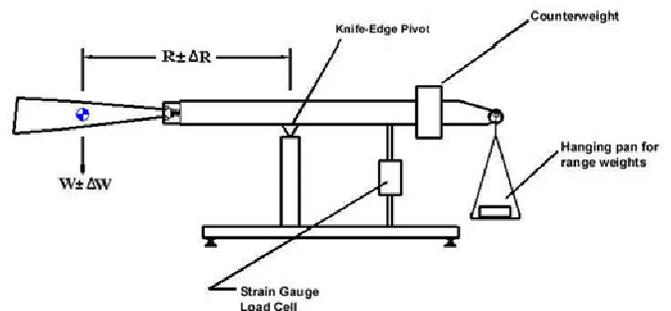


Figure 11. The Schematic Diagram Shows the Use of a Knife-Edge Pivot in a Moment Weight Scale [18]

Based on the results of this project, the ranking of the selected materials was: 1) tungsten carbide with a CO₂ footprint of 4.44 lb/lb; 2) silicon carbide with a CO₂ footprint of 6.25 lb/lb; and, 3) boron carbide with a CO₂ footprint of 8.25 lb/lb. Figure 12 shows the mapping of selected materials in an energy – CO₂ space.

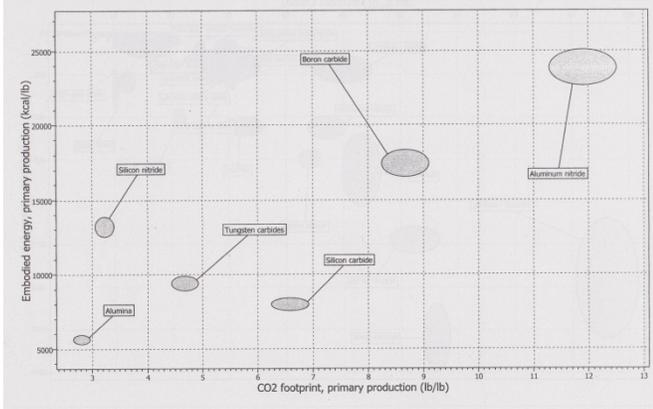


Figure 12. CES Edupack Mapping of Selected Materials for Knife-Edges and Pivots

Project 2: Materials for a Fresh-Water Heat Exchanger

Heat exchangers typically consist of a set of tubes through which one fluid is pumped then immersed in the chamber through which the other fluid flows; heat passes from one fluid to the other. The material of the tubing must conduct heat well, have a maximum operating temperature above the operating temperature of the device, not corrode in the fluid, and—since the tubes have to be bent—have adequate ductility. Figure 13 shows an example of a U-tube heat exchanger.

Requirements

- Maximum service temperature > 150 °C (423 °K)
- Elongation > 20%.
- Corrosion resistance in fresh water: very good.
- As large a thermal conductivity as possible.
- Select two or three of the best materials and rank them by their ECO properties.

Based on the results of this project, the materials selected were: 1) copper with a CO₂ footprint of 4.9 lb/lb; 2) non-age-hardening wrought Al alloys with a CO₂ footprint of 11.2 lb/lb; and, 3) brass with a CO₂ footprint of 6.5 lb/lb (brass has a lower thermal conductivity than non-age-hardening wrought Al alloys). Figure 14 shows the energy-CO₂ space for ranking materials for the heat exchanger.

Plastics: A Junior-Level Course

The course emphasizes plastics properties and selection, plastics testing based on the American Society of Testing and Material (ASTM) standards, and plastics processing. The principle of sustainability that was considered in the

course was the use of renewable resources in place of the traditional petroleum-based plastics. Specifically, a project entitled “The Effects of Clay Nanoparticles on Polylactic Acid” by Brian Baker, Karl Rauchenstein, and Kyle Ravenscraft examined how incorporating clay nanoparticles into PLA could influence the mechanical properties of the resulting polymer-clay nanocomposite. Polylactic acid (PLA), a biopolymer, is claimed to have similar properties as commercially available polypropylene (PP).

U-tube heat exchanger

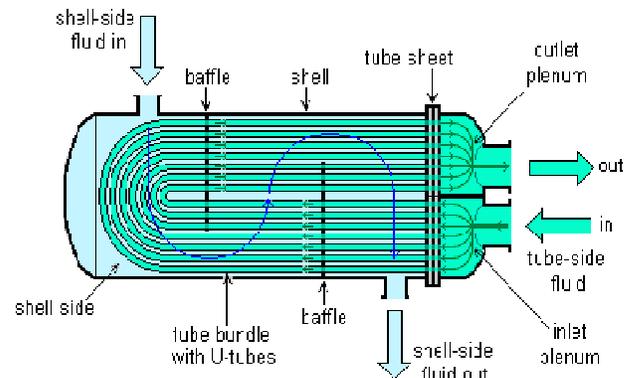


Figure 13. A U-Tube Heat Exchanger [19]

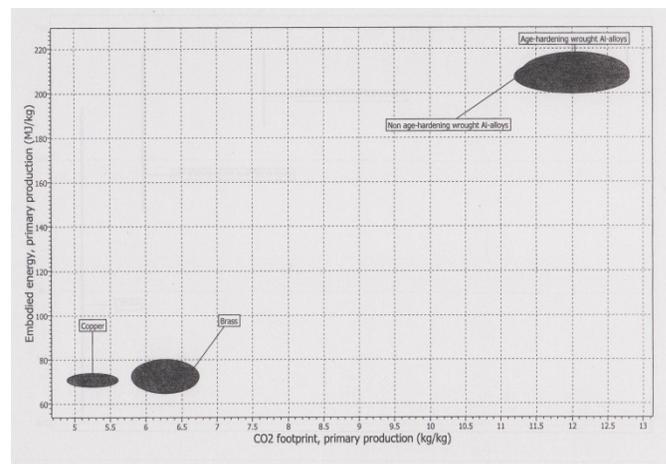


Figure 14. CES Edupack Mapping of Selected Materials for U-Tube Heat Exchanger

Materials

Plastics: polylactic acid (PLA), Ingeo 3251D™, manufactured by NatureWorks® Clay Nanoparticles: Cloisite® 20A, a natural montmorillonite modified with a quaternary ammonium salt manufactured by Southern Clay Products, Inc.

Equipment

A Davis Standard DS-125 extruder was used for melt-compounding PLA and nanoparticles.

A 60-Ton Sandretto Injection Molding Machine was used for preparing ASTM test specimens.

Polymer-clay Nanocomposites

PLA-clay nanocomposites with the following compositions were successfully melt-compounded.

Table 1. PLA-Clay Nanocomposites Compositions

| Composition | Weight % of PLA | Weight % of |
|-------------|-----------------|-------------|
| 1 | 100% | 0% |
| 2 | 99% | 1% |
| 3 | 99.5% | 0.5% |
| 4 | 99.25% | 0.75% |

Injection Molding of Test Specimens

The injection molding of virgin PLA, composition 1, was done successfully; however, it was difficult to injection mold test specimens with compositions 2, 3, and 4. The nanocomposites became brittle and broke off in the sprue of the mold, which made the molding of sufficient test specimens difficult. Because of this difficulty, the melt-blending step was skipped and a 97/3 weight % mixture of PLA and clay was directly introduced into the injection molding machine and test specimens molded. The processing conditions used for the injection molding of the test specimens were:

| | |
|-------------------------------|-----------|
| Drying temperature | < 110 °F |
| Drying time | < 6 hours |
| Rear temperature | 300 °F |
| Middle temperature | 330 °F |
| Front temperature | 350 °F |
| Nozzle temperature | 350 °F |
| Processing (melt) temperature | 370 °F |
| Mold temperature | 90 °F |
| Back pressure | 100 psi |
| Screw speed | 75 rpm |

Based on the results of this test, there was no significant difference between the modulus of elasticity of the virgin PLA at $159,360 \pm 6998$ psi and that of PLA/clay nanocomposites at $161,640 \pm 4606$ psi. The flame test based on ASTM D 3014 showed no significant difference between the control and the PLA-clay nanocomposite specimens, as

shown in Figure 15. This result suggested that there were exceptions to the general claim that polymer-clay nanocomposites have flame-retardant properties. Certainly, this claim was not observed in the PLA-clay nanocomposite studied in this work.

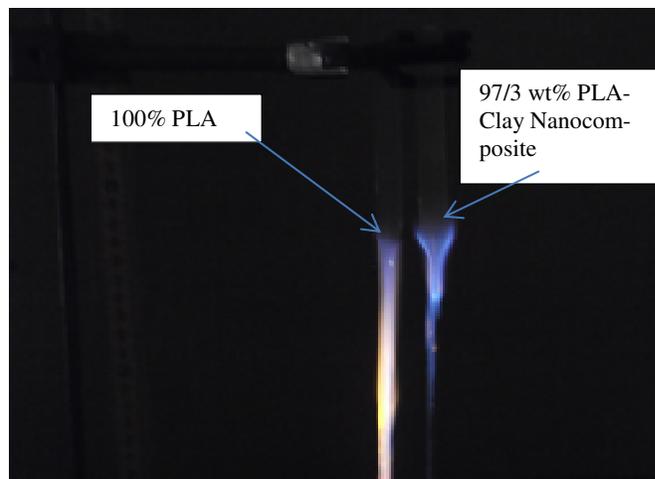


Figure 15. A Flame Test for Neat PLA and 97/3 wt% PLA-Clay Nanocomposite

Assessment

Two instruments, a course examination and a general survey, were used to assess student knowledge of sustainability. In the plastics course examination, the average score on sustainability questions was 80%. The course examination questions were specific to materials covered in class about sustainability. In addition to the course examination, a general survey (see Appendix A) was used to assess student awareness of sustainability beyond materials covered in class. In other words, the survey sought to assess how learning about sustainability was going on beyond materials covered in class. To put the survey in context, the authors would like to inform the readers that this Midwestern university prides itself on being the owner of the largest geothermal project in the U.S. Thus, it was anticipated that students would be aware of the subject beyond materials covered in class. The results of the survey suggested that more work was required to increase student awareness about sustainability above the current 64% level to at least 80%.

In subsequent years, the authors plan to use the survey differently. That is, they plan to administer the survey in the first week of the semester and during last week of the semester. The results of the survey given at different times in a semester will be compared in order to determine if there were any improvements in student understanding of sustainability due to the materials covered in class.

Conclusion

MET students were exposed to three aspects of sustainability; namely, recycling, CO₂ footprint (a measure of the impact of human activities on the environment), and the use of renewable resources. Students were introduced to these sustainability concepts through individual and team projects. When examined over the materials covered in class, students scored an average of 80%, indicating that they fairly understand the concepts of sustainability. However, when a survey was used to examine if learning was taking place beyond the classroom, the same students scored an average of 64%, which indicated that more work is needed to increase MET students' understanding of sustainability. In this vein, the authors plan to augment the current project approach with product lifecycle analyses. This will enable the students to assess the contribution of each stage of product manufacturing to sustainability. Thus, sustainability will be used as a tool to determine the acceptability of a design or a processing technique toward the manufacturing of a product. The Okala Life Cycle Analysis calculator is being explored for this purpose.

It was assumed that the approach adopted at this Midwestern university to promote sustainability and sustainable development among MET students was applicable in most academic institutions, particularly in academic institutions where there are no centralized efforts to incorporate sustainability and sustainable development into their undergraduate programs. This approach will give educators the freedom to be creative in developing teaching methods that best suit their specific environment in teaching sustainability and sustainable development.

Appendix

The survey and its results are included here for your review.

1. _____ is home to the nation's largest closed geothermal energy system. Geothermal means:
 - a. Water cooled.
 - b. Energy derived from the heat of the earth.
 - c. Energy pulled from the outside air.

Result: The correct answer is b. Ninety-five percent of the respondents picked this answer correctly, while 5 percent selected c. as their response. No one chose answer a.

2. Much has been discussed about "climate change" in the media. The primary cause of climate change is:
 - a. Changes in the solar system.

- b. Historical changes in the atmosphere. The earth is constantly warming.
- c. Global warming brought about by heat-trapping emissions released into the air.

Result: The correct response is c. with 65 percent of the respondents choosing that answer. Thirty percent chose answer b. and 5 percent did not respond to the question. No one selected a.

3. Plastic bottles and the leeching of toxic chemicals into bottled drinks have been the subject of news articles and recent documentaries. BPAs are one of the main causes of concern. BPAs are:
 - a. Bisphenol A.
 - b. Bio Aminos.
 - c. Bicloric Acid.

Result: The correct response is a. with 65 percent of the respondents choosing this answer. Twenty percent chose c, and 10 percent chose b. Five percent did not respond.

4. Bottled drinking water is a huge industry. The bottled water industry has come under fire recently because
 - a. Bottled water is subjected to lower standards than tap water.
 - b. Bottled water contributes to large amounts of oil-based plastics being deposited in landfills.
 - c. Both a. and b.

Result: Sixty-five percent of the respondents chose the correct answer c. Twenty-five percent chose b, and 10 percent chose a.

5. Manufacturers are increasingly aware of "sustainable manufacturing." Sustainable manufacturing includes:
 - a. Increased manufacturing costs.
 - b. The responsible use of resources.
 - c. Both a. and b.

Result: Sixty percent of the respondents chose the correct answer b. Twenty-five percent chose c, and 15 percent did not respond. No one chose a.

6. Many of our plastic products are manufactured from petroleum bases called polymers. There are new sources of polymers called biopolymers. Instead of petroleum, biopolymers are produced from
 - a. Living organisms.
 - b. Water.
 - c. Sand.

Result: The correct answer is a. and was chosen by 45 percent of the respondents. Thirty-five chose b, and 10 percent chose c. Fifteen percent did not respond.

7. Using biopolymers in the production of plastic products has the following effect:
 - a. Biodegradability in landfills
 - b. Less reliance on petroleum.
 - c. Both a. and b.

Result: Answer b is the correct answer with 65 percent of the respondents making this choice. Twenty percent chose a, and none of the respondents chose b. Fifteen percent did not respond

8. Companies that use designs and process in manufacturing that are environmentally friendly experience the following to their bottom line:
 - a. Higher costs.
 - b. Lower costs.
 - c. Higher costs now, that leads to lower costs in the future.
 - d. All of the above.

Result: Fifty percent of the respondents chose the correct answer which is c. Fifty percent chose a while 5 percent chose b. Fifteen percent did not respond.

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HOW TO ESTABLISH SUCCESSFUL INTERNATIONAL EXPERIENCES FOR ENGINEERING AND TECHNOLOGY STUDENTS

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Abstract

In today's global world, an international experience is vital to engineering and technology students' undergraduate or graduate education. The authors of "The Engineers of 2020" indicated that future engineers must be able to work in a dynamic global economy [1]. Educators must help students take necessary measures to adjust to a changing, global world. Providing students with a variety of options for international experience is the key to getting students closer to this goal. The main objectives of an international experience are to provide students with practical experience in their fields, encourage students to develop foreign language skills in order to be better prepared for global competitiveness, introduce students to other countries' business and industrial practices, and help students understand and appreciate cultural differences both abroad and at home.

One option for students is the study abroad program; these programs can range from a one-week to semester-long course. Another option is an international internship, which is popular with students who already have strong foreign language skills. Finally, there are short, study abroad courses and non-credit events that focus on service learning. In this paper, the authors give examples of several of these international experiences and discuss how the programs were established, how they are run, how they can be duplicated, and their strengths, weaknesses, opportunities, and threats.

Study Abroad with Service Learning Component

Indiana University Purdue University Indianapolis (IUPUI) operates a study abroad, service-based program through an umbrella organization known as Global Design Students (GDS). This student-run organization primarily operates through the dedication of students and faculty in Engineering Technology at IUPUI within the specific disciplines of Architectural Technology, Interior Design, Computer Graphics Technology, Construction Engineering Management Technology, and Organizational Leadership and Supervision. However, GDS encourages students in all dis-

ciplines across campus and from sister institutes and countries tied to local GDS chapters to participate in the program.

GDS operates on the principle of establishing service learning and community-based educational opportunities at local, national, and international levels, allowing students to vary their involvement based on their availability and financial status. Project ideas are initiated by the community to meet a local need, and the scope is negotiated to meet a time frame. Projects are typically design-based and have involved the entire spectrum of the design continuum from conceptual design to actual construction, depending upon the specific problem at hand.

One such GDS service learning project was in Thailand and involved a partnership between two host universities. This study abroad program, which evolved from many GDS projects in southeast Asia, can also reach out to all of the institutions within the GDS community. Thus, students from several universities and countries are encouraged to participate, providing a more global, cross-cultural experience than is typically experienced abroad.

This service-based program operates under the model of what Chisholm—in Jones and Steinberg [2]—refers to as a "sandwich structure" in which the in-country component of the course is wedged in between two segments that are offered at the home institution. Several introductory sessions related to the culture and language of the host country precede travel and are followed by reflective and summary sessions upon return. The in-country component, in this instance, is not lengthy—primarily due to expense, sensitivity to the burden upon the host institution, and the overload of new experiences faced by students and faculty. It has proven to be an appropriate length of time for first-time travelers and consists of two, one-week sessions at each host university. The experience involves a refined mixture of community design projects, cultural immersion, and unstructured time that allows students to rest, reflect, and explore the country at their own pace relative to their specific interests.

The design workshop at each institution is focused on in-country environmental stewardship and sustainable design

concerns and is developed and primarily taught by the host institution. This immediately immerses the visiting students into the language and local environment, as well as teaching pedagogies that may be unfamiliar to them. Unfamiliar should not imply inferior; Chisholm further noted that:

...faculty from host-country institutions are likely to be more knowledgeable about the local culture and current events and that students' learning will be enhanced by employing host-country expertise. Studies at a host institution can also provide students with exposure to a different type of educational system. (p.91)

Chisholm [2] warned that “avoiding the use of host-country faculty may unintentionally suggest home-country superiority to students.” This is a particularly sensitive issue when visiting third-world countries that are often initially viewed by students as lagging behind their own country on many levels. Students need to be aware that host countries have adapted local realities to solve local issues and that these adaptations (differences in culture, economics, methods, etc.) may help determine solutions to their own current or future issues or adaptations.

The strengths of this program lie in its ability to combine experiential design knowledge with hands-on leadership skills. Its international, community-centered focus also serves to strengthen student résumés and, as several participants stated, these international experiences have often served as key talking points within a job interview. Employers often see this as an opportunity to discuss multiple skill sets and the personal interests of applicants.

Immersion within a local community also helps to engage students with the local wisdom and to see a new climate and culture beyond “... the fog of our own cultural lenses”. Moore [3] goes on to note that “placing service learning in a global context assists with providing the types of international experiences that transcend tourism or travel-study experiences.” Sutton [4] adds to this: “...one comes to understand how life is lived from the perspective of those living it.” The focus on environmental stewardship is also in keeping with what Musil [5] emphasizes as having been identified as a problem within current models of study abroad: “Global education is overwhelmingly approached in cultural terms rather than through a focus on such issues as economic disparities, environmental sustainability, health and HIV/AIDS, security, human rights.” Not only is a focus on sustainability a topical global issue, it also can improve a student’s collective sensibility for how to take care of the parts of the planet far removed from his or her homeland.

The threats to and weaknesses of any program like this primarily lie in the affordability of the experience and the possibility that host institutions may cease to accommodate this type of program. Universities considering adopting such a study abroad model should also carefully consider the number of these opportunities posed to students so that programs do not cannibalize each other. Cannibalization often occurs because there are a limited numbers of students (due to finances, work, family, etc.) that can participate and the course minimum limit may not be met due to excess program choices. As programs of different types surface, the owner of the new program should take the initiative to ensure that cannibalization does not occur. Existing program faculty should also take the initiative and determine if new partnerships may enhance programs that currently exist.

This model of international experience has proven to be successful as it incorporates many hands-on learning skills embedded within a foreign country and culture. Communication, team work, organization, diplomacy, and professionalism are all new skill sets above and beyond discipline-specific skills that are fostered in this environment and that so adeptly mirror the type of industry experiences that graduates will face within their future professional lives. Universities owe students this valuable opportunity and should strive to build and maintain more of these types of transformative and rich educational experiences.

Study Abroad: Engineers Without Borders Program

IUPUI has an initiative to more deeply engage students in service and experiential learning and to include international experiences in college life, with the goal of inspiring life-long learning as well as intellectual and professional development. One method of implementing this goal was to start a local chapter of Engineers Without Borders (EWB), a national and international organization that acts as a clearing-house for grass roots, community developed project ideas. EWB-IUPUI is a volunteer student organization, with members from a large variety of majors; past members include engineering, technology, science, business, and marketing. The Study Abroad Program was initially set up to meet only the international element of IUPUI’s initiative but with future plans to also provide classes so that the program meets the service learning definition set forth by Bringle [6] which states:

We have service-learning as a credit-bearing educational experience in which students participate in an organized service activity that meets identified community needs and reflect on the service activity

in such a way as to gain further understanding of the course content, a broader appreciation of the discipline, and an enhanced sense of civic responsibility. (p.222)

These classes will be part of a sustainable technology certificate/degree. The holistic approach (appreciation for a non-native perspective on economic, social, environmental, technical, etc.) discussed by Lewin [7] is still being developed. As an interim to the ideal, the authors of this current study have offered a non-credit study abroad event which addresses economic, social, and technical issues.

As a first step, the faculty and student organization selected a project in Santo Domingo, Ecuador, to design and build a community center and educational facility for Luz y Sombra, the local association for the blind. The EWB Study Abroad Program allows a small portion of the students to travel to Ecuador for needs assessments and implementation trips, while the majority of the students remain in the U.S. to work on the design aspects. In order for students to qualify for the trip, they must be very involved in the project design, attend cultural awareness seminars, attend skills training workshops, and help raise funds for the project. The cultural awareness seminars have been conducted by students from South America, academic/business volunteers with experience in Ecuador, and a volunteer architect from Chile. The skills workshops are directly coupled to the project requirements; in this case, designing and building a community center and educational building means working with soils, concrete, block masonry, etc., so workshops were conducted locally with experts from engineering and construction firms. Some were involved with EWB-USA professional chapters, and others were simply interested individuals and companies; wherever they are found, their participation is critical. These interactions help the intellectual and linguistic student development, as discussed in the holistic model, which are further enhanced for the students who actually travel abroad [7].

To date, thirty-nine students have been involved with the project and three have traveled to Ecuador on a needs assessment trip. The team on this first trip was composed of a medical doctor, an architect, a structural engineer, an electrical engineer (professor and faculty advisor), one student from interior design, and two students from mechanical engineering. The purpose of the first visit was to determine what the community (both the association for the blind and the larger community) needed, wanted, and expected from the project, as well as to determine in collaboration with the community the priority for each of these needs. In this case, the community's needs were in line with their wants so the next step involved collecting data (soil samples, site meas-

urement, grades, etc.) about the proposed site for the structure, determining what the community would provide and what the club would provide, and educating each other about realistic expectations for the project timeline, resource availability, etc. Most of the Luz y Sombra members participated in both cultural and technical meetings as well as with various municipal leaders, local professionals, and important groups from the wider community, including radio and television interviews and participation in a festival with the local Colorado native tribe. The team toured local construction sites and visited local hardware and equipment rental stores to determine availability of local resources for a sustainable design. After exchanging gifts with Luz y Sombra at a parting festival, the team spent another day immersed in the culture of Ecuador by touring the countryside, crossing the equator, seeing parks and monuments, and exploring regional foods and markets. A year later, preliminary designs were ready and there was a plan to return to Ecuador to receive community feedback.

The plan to use EWB within the university structure has several strengths and weaknesses. EWB has already developed relationships with numerous communities around the world, as well as local, non-government organizations that typically write project proposals, so they provide instant access to international projects. They have also set up review boards to verify that projects are developed with safety, security, good engineering design practice, and appreciation for the needs and desires of the local community. They provide a network of experts in all project facets that are accessible and willing to volunteer for international projects. These volunteers mentor students, employ good design practice appropriate to the location, and travel on assessment, communication, and implementation trips. However, there are some obstacles such as dues and fees associated with joining a national organization and having projects reviewed, duplication of paperwork for EWB and the Study Abroad office, the time-consuming process to acquire projects, duplication of effort to obtain permission for travel, and a large number of forms, proposals, and reports for the pre/post trip. These obstacles are especially risky for faculty engagement when the faculty member is on a tenure track. As of 2010, 96% of university promotion and tenure policies do not reward international engagement [8]. Most of the weaknesses condense to extra time, which if left unaddressed by university policy, make international engagement a serious risk for tenure-track faculty career advancement. Universities must determine if they truly want international engagement and, if so, to turn rhetoric into policy, focused grants, course release time, etc. The strengths and weaknesses must be weighed at each institution with an eye on resources and risks. The engineering and technology department at IUPUI has and continues to do projects both

with and without EWB, depending on resources (knowledge, finances, etc.), project scope, and risks (legal, safety, etc.).

Study Abroad with University-Industry Cooperative Learning

Ten years ago, a course entitled GO GREEN (Green Organizations: Global Responsibility for Economic and Environmental Necessity) was developed to teach engineering and technology students at IUPUI about sustainability in business and industry in Germany. GO GREEN represents an excellent example of an international, university-industry cooperative learning experience for students. It provides one approach to integrating sustainability into the engineering curriculum, primarily through an experiential, interdisciplinary, international approach.

The Accrediting Board for Engineering Technology has identified several program-level learning outcomes to which both sustainability and international/cross-cultural learning apply, including an understanding of professional and ethical responsibility, the broad education necessary to understand the impact of engineering solutions in a global societal context, a knowledge of contemporary issues, and an ability to use the techniques, skill, and modern engineering tools necessary for engineering practice [9].

Upon completion of the GO GREEN course, students will have:

- acquired knowledge of issues in sustainability as they relate to business and industry internationally and nationally;
- examined and evaluated case studies of sustainable practices in business and industry;
- visited international organizations that practice sustainability to gain first-hand knowledge of operations;
- identified trends and business practices in various sustainable organizations;
- utilized information from the course to apply sustainable knowledge in the workplace upon return;
- acquired some knowledge of German culture and language; and,
- understood and analyzed the interconnectivity of global concerns.

Germany was selected as the focus of this course because, for over thirty-five years, Germany has been considered an expert in sustainability, with numerous laws and regulations concerning environmental issues and practices in business and industry. Sustainability is now an essential part of the

German culture. There are three legs of sustainability—environment, economics and society; most German organizations look at all three when making decisions, and they are generally weighed equally. This is sometimes called the “triple bottom line” [10].

The GO GREEN course was designed to reduce barriers for students with respect to both time and money. Students travel to Mannheim, Germany, for approximately seven days. The class visits German businesses, industries, or municipalities to view and hear about sustainable practices. Past visits have included Daimler, Roche, MVV Energie, BASF, Bayer, and Volkswagen. In addition, solar research facilities, a solar factory, solar cities, wind turbines, solar boats, and various other renewable energy-related industries and facilities have also been included.

For the GO GREEN course, students purchase their own airline tickets and make their own accommodation reservations. The course was set up this way in part to teach students responsibility and how to get around on their own. Most of the students who enroll in this course are first-time visitors to a foreign country. With a well-documented pre-departure class, students are prepared to find their way through Frankfurt airport to the train station and then to Mannheim. These processes allow the students a level of freedom that allows them to feel comfortable in their surroundings. This also allows the students to start interacting with German people and culture immediately upon their arrival. GO GREEN students do not have to know the German language to participate in the course; though some culture and language skills are taught in the pre-departure course.

Once students complete the course, most will say that they want to go back. IUPUI offers a summer internship program with the Duale Hochschule Baden-Württemberg Mannheim. Engineering and technology students with five credit hours of German language can apply for a ten-week summer internship in or around Mannheim. Engineering students can take it one step further by earning the dual degree of German and Engineering at IUPUI. Generally, these students will do a one-semester internship in Heilbronn, Germany, facilitated by the Heilbronn University of Applied Sciences. They can also spend one additional semester taking courses at the university.

Three threats for duplication of study abroad opportunities like GO GREEN include: curriculum, students, and partners. Curriculum issues include the identification of sustainability as a teachable concept and its relationship to other engineering and technology curriculum concepts. Thus, for courses in sustainability such as GO GREEN, care

must be taken to link assignments, readings, and activities to existing assessment processes designed to document student learning outcomes. Equally important is the need to explicitly, intentionally, and continually stress the integration and application of sustainability to other engineering and technology courses and concepts.

Student issues include the identification, selection, and preparation of students to participate in a course such as GO GREEN. Finding students with an interest in environmental aspects of engineering and technology and equipping them with knowledge of sustainability is paramount if their learning is to be maximized. Additionally, adequate preparation for international travel and cross-cultural experiences must be provided, and funding and other logistical issues must be reconciled. For students interested in studying sustainability in-depth, how to sufficiently engage in undergraduate, field-based research must be determined.

Partner issues are most important because so many activities in a course like GO GREEN would simply be impossible without the support and interest of companies and organizations involved in sustainability. Clearly, IUPUI has benefited from the use of a host country, academic affiliation with Duale Hochschule Baden-Württemberg Mannheim, Heilbronn University of Applied Sciences, and University of Kaiserslautern, and the forging and expansion of those relationships that have occurred over several years. Such in-country affiliations have been useful in the identification of partners and in handling some of the minor logistics. In the experience of GO GREEN faculty, most industry and business partners have been eager to showcase best practices, educate students about sustainability and, in many instances, permit undergraduate students to be involved in field-based research. Flexibility on both sides concerning dates, times, activities, etc., can go a long way toward maintaining and enhancing an ongoing relationship. Finally, any case-specific issues such as proprietary information, security clearances, or accommodations for individuals with disabilities, should be acknowledged and resolved prior to the experiential learning component of the course. Properly arranged and managed, an international course in sustainability can truly become sustainable, but not without an ongoing sense of purpose and commitment by all stakeholders involved, a lesson that holds equally true for the concept of sustainability itself.

Conclusion

These three different models of short, study abroad programs for students are excellent examples of what can be established in order to give engineering and technology students an opportunity to contribute in community service or

learn about particular subject matter, while experiencing and learning about a different culture. Students in the various programs appear to have been enriched from the experience of being exposed to persons from a different culture and country, both personally and professionally. Having completed one of these programs, the students experience strong growth in their leadership skills, cross-cultural knowledge, interpersonal skills, and ability to compete in an increasingly interconnected world. Most importantly, however, it inspires the students to become active participants in a civil society. Thus, every effort put into the program is rewarded in many ways.

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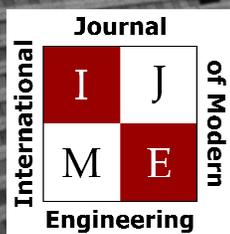
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