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THE TECHNOLOGY INTERFACE INTERNATIONAL JOURNAL EDITORS

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A Hands-On, Practical, and Fun Method for Teaching Lean Through Process Simulations

Philip Weinsier, TIIJ Editor-in-Chief

With so many publications already in the literature on lean manufacturing, why do I need to read yet another one? Everyone who's ever heard of lean already knows that the five-step principles are 1) identify value as seen by the customer; 2) map the value stream and eliminate steps that do not create value; 3) create a tight sequence of product flow; 4) establish pull from the next activity; and 5) continue the process until perfection is reached. So what's new here? I'm glad you asked. In order to introduce the study in this issue, let's look briefly at process simulation and modeling. For most people, these terms conjure up thoughts of computer simulations. But computer simulations are in vogue these days because, well, they work, and you don't have to look very hard to find software packages that allow you to simulate common industry problems related to defects, product resource waste, and quality control. But simulation doesn't always have to be on a computer; there are also paper-based activities and games that the students can play.

The basic concept of six sigma is to model an accurate system for measuring process defects so that they can be eliminated in the real world. Similar to basic engineering principles, you come up with an idea for a better mousetrap, you run your idea through simulation software, then build a prototype of the model and see how well it actually catches mice. A defect, continuing the analogy, might be that after having caught three mice, some part of the trap breaks. After some head-scratching and more simulations, you build and test your beta version, only to find that the trap material deforms after now six mice, thus allowing the little varmints to escape. And product resource waste? Perhaps you're building a trap that's large enough to catch small bears, when in fact you only need one sized for a mouse. Quality control: After coming up with, say, a *psi* version that seems to work as conceived, you start manufacturing them for sale, only to find that customers are starting to return them. What happened? Well, did you check with the suppliers of your materials to make certain that their materials wouldn't degrade before the end of your intended lifespan for the product?

But let's get back to the learning aspects of lean. How do people learn best, or perhaps most efficiently? Traditional lecture; blended learning; flipped classroom models; role-play exercises? I don't have enough room here to talk about all of the different ways that people learn. And, we already know that no one method works best for everyone. We also know that each method can be tuned, tweaked, or modified to yield the best results from a specific audience. So let's turn to the model proposed by Dr. Brodke to see why this combination of format and substance may well be the best all-around process simulation model for learning lean principles and, ultimately, being successful in implementing those principles.

Looking in from the outside, and judging by published studies, one would believe that lean is alive and well, and that companies are at the top of their respective games. In fact, failure rates for lean implementations are reported as being as high as 50%, in some cases even higher; obviously unacceptable, when one considers the cost of training staff, changes in processes and tools, and even just updates to software. And, in spite of imparting effective leadership skills to managers, studies also report that those skills don't always trickle down to the lower-level managers, the people who actually oversee what happens at the worker level.

My area of expertise does not include lean manufacturing. However, I did participate in several of these process simulation events presented by the author, and came away with a profound appreciation for her approach to the simulations. They were small enough (8-15 participants) to allow us to work and interact with each other; but, more importantly, to see how logistics, along with our own actions and those of the others, affected the on-going process in real time. At each of these events, the model changed—one time we simulated a hospital scenario—but the process was the focus. In fact, the models can easily be understood by people from virtually any field. That is, you learn the "process," what can go wrong and how to fix it, not how to run a hospital.

Finally, in the author's model, participants at all organizational levels are allowed to be frustrated, learn, try, fail, and try again in an environment that is fun, low-risk, and related to, but not the actual, work environment. As with the hospital scenario, the participants don't learn how to run a hospital; they learn what to do if a defect is encountered, if there are wasted resources, and how to look for and evaluate quality control. Participants gain first-hand experience of trusting each other to recognize problems, develop solutions, and implement changes in order to maintain the continuous improvement mindset required by lean.

Editorial Review Board Members

INTRODUCING ENGINEERING AND TECHNOLOGY MAJORS TO NANOSAFETY AND ETHICS

Dominick E. Fazarro, University of Texas at Tyler; J. Craig Hanks, Texas State University; Jitendra Tate, Texas State University; Walt Trybula, Texas State University

Abstract

In this paper, the authors report on their work developing and implementing a set of modular courses initially developed to help foster ethical awareness in the next generation of engineers. New knowledge, new techniques, materials, systems, and devices have brought new industries, new social forms, and new ethical challenges. One important aspect of technological societies is the intentional pursuit of change and of new technologies. This requires that responsible engineers have heightened awareness of the health and safety risks, ethical and social considerations, and environmental and humanitarian implications of their work. Through an NSF-funded project, an introductory and advanced curriculum was developed and tested for online and face-to-face course modules taught as full courses or infused into existing courses. Drawing on the guidance of an advisory council, project personnel researched, developed, and tested courses and modules. The advisory council included experts from industry and academia. One important aim of the project was the identification, recruitment, engagement, preparation, and encouragement of students from traditionally underrepresented groups into careers in science and engineering, with a focus on nanotechnology. In this paper the researchers briefly survey the origin of the project, present some pedagogical considerations and how the researchers developed the course modules, and review the deployment of these modules and the feedback from the first two years.

Introduction

In the last decade, nanotechnology has made numerous inroads into mainstream society through products such as coatings on cell phones, antimicrobial socks, static-free pants, self-cleaning toilets, automobile paints, solar paint, lighter and stronger baseball bats, lighter and damage-tolerant wind turbine blades, and fuel cells. More efficient methods of producing nanomaterials have been developed and production volume has increased. These efforts are bringing down the cost of nanomaterials. As the cost of nanomaterials decreases, more products using nanomaterials are being developed. However, tomorrow's engineers and technologists will also need to responsibly establish guidance for the safe handling of nanomaterials and for safeguarding the environment. In the absence of specialized training in issues related to health, safety, and environmental impacts of nanotechnology, the tendency will be either to focus only on optimizing performance and costs, while incorporating nanomaterials without regard to health and safety concerns, or to be overly cautious and avoid using nanotechnology. Since nanomaterials are a new class of materials, there exists a degree of uncertainty about long-term effects on health and the environment [1], which adds complexity to decisions about the use of nanomaterials. However, as noted by Marchant et al., "simply waiting for these uncertainties to be resolved before undertaking risk management efforts would not be prudent" [2]. For these reasons, the quest to unlock the maximum potential of emerging, and potentially game-changing, nanotechnologies brings with it the need to anticipate and reduce negative consequences. To prepare the next generation of engineers and technologists to address these challenges requires education in identifying, evaluating, and responding to health and safety risks, ethical implications and issues, and environmental and social impacts.

There is a pressing need to investigate safety issues around the use of nanomaterials [3, 4]. The British Royal Academy of Engineering states that the possibility of negative environmental, health, and safety impacts from nanotechnology represents the most urgent concern about nanomaterials [5], and the United Nations urges greater attention to risks of nanotechnology [6]. A 2006 report from UNESCO states, "The most pressing near-term issues related to nanotechnology are toxicity and exposure to humans and the environment" [7]. To date, most nanoenvironmental health and safety (nano-EHS) research has consisted of acute toxicity tests in cell cultures, and much of it has focused on inhalation as a potential route of exposure [8, 9]. However, other exposure routes such as ingestion, absorption, and injection also exist.

For instance, certain engineered nanomaterials (ENMs) have been shown in animal studies to translocate along the olfactory nerve into the brain [10,11], to cross the placenta, and to penetrate damaged or diseased skin. Once inside the body, certain ENMs have induced inflammatory responses, cardiovascular effects, pulmonary fibrosis, and genotoxicity [12-17]. Moreover, some carbon nanotubes—one of the most widely researched classes of ENMs from both a technological and toxicological perspective—have even been shown to induce asbestos-like effects in rodents [18, 19].

While the effects of one type of ENM in one laboratory study should not be generalized to other ENMs, the hazard literature as a whole supports caution. NIOSH (2009) stressed that, "nanomaterials present new challenges to understanding, predicting, and managing potential health risks to workers as with any material being developed, scientific data on health effects in exposed workers are largely unavailable" [20]. According to the Nanotechnology Law Report of Summer 2009 [21], the EPA provided two proposed Significant New Use Rules (SNUR) under Section 5(a) of the Toxic Substance Control Act (TSCA) for multi-walled and single-walled carbon nanotubes [22]. These revisions to the law have significant implications that will lead to new safety standards to ensure the safety of workers, minimize future litigation, and address public skepticism about nanotechnology. In a 2005 report, *Nanoforum* urges us to identify and understand the risks, to specify what knowledge should be shared, who should have access, and to protect the public [23].

Safety issues in nanotechnology, including toxicity and risk, are sometimes narrowly understood as simple technical issues. However, from the beginning of the National Nanotechnology Initiative in the U.S. [24], research has focused on the multiplicity of factors that influence safety. Research indicates that safety concerns are inseparable from policy, ethics, economic, environmental, and regulatory concerns [25-29]. Thus, addressing safety concerns requires that these concerns be placed in a broader context. Beyond research on nano-EHS, educational efforts are needed to prepare nanotechnology researchers and workers, and to inform citizens in a world where nanomaterials play an important role [30-33].

Professors at two public four-year Carnegie Masters-L public universities in the southwest, one of which has a new Materials Science and Engineering doctoral program, took a proactive approach and created a proposal to the Nanotechnology Undergraduate Education Division of The National Science Foundation (NSF). The goal of the project was to prepare students to make informed and knowledge-based decisions about when and how to use nanomaterials, which materials to use, how to ensure a safe workplace, and how to identify and evaluate environmental impacts. Special attention was given to creating learning situations and materials conducive to nurturing members of underrepresented groups in the study of technology and engineering [34, 35], and to encourage consideration of real-world experiences [36]. The initial funding period was two years, (summer of 2012-2014), with an extension approved through 2015.

Goals and Objectives of the Project

The primary goal of the project was to educate engineering and technology undergraduate students in nanotechnology safety, including societal, ethical, environment health, and safety issues [25-27, 37, 38]. Teaching these topics supports the importance assigned by the CDC National Institute for Occupational Safety and Health to understanding, predicting consequences, and managing current and new nanomaterials. Additionally, the modules developed serve ABET student learning outcomes, including as ethics, environmental issues, knowledge of contemporary issues, and lifelong learning. The two institutions developed objectives that were feasible and did not overcommit the faculties' ability to conduct the project effectively. The objectives were

- Develop two modular undergraduate-level courses dealing with nanotechnology environment, health, ethics, and safety awareness, which would be offered in their entirety online to Institution One students, and as modules inserted separately into other courses to Institution Two students. These courses will better prepare undergraduate students to advance to graduate nanotechnology programs and to work with nanomaterials in their future careers.
- Build on pedagogical research by employing a variety of teaching methods to engage students, particularly women and Hispanic students, including hands-on training, socially relevant case studies, plant tours, videos, and guest lectures.
- Elucidate emerging needs in nanotechnology environmental health and safety, and incorporate them into basic education that can be immediately employed in industry.
- Promote interdisciplinary interactions among engineering, engineering technology, science, and industrial management/technology majors.
- Develop interdisciplinary and multi-institutional research teams.
- Assess the effectiveness of the newly developed curriculum using a rigorous formative and summative assessment plan.
- Establish a Nanotechnology Advisory Council that will assist in providing current information related to research and tools in nanotechnology environment health and safety, and ensuring that the educational efforts serve the needs of industry.

Student Demographics

The project targeted the minority population of Hispanic and African American undergraduate students at two four-year universities in the Southwest. Women were also targeted to participate in the project at both institutions. Students participating in the project majored in industrial technology, manufacturing, engineering technology, electrical, mechanical, civil and environmental engineering, construction management, and concrete industry management. During the 2012-2014 academic school years, the project impacted over 1200 students.

Construction of Modules

Modules were developed by the grant team and carefully reviewed by the Nanotechnology Advisory Council (NAC). The NAC consisted of upper-level managers and researchers from industries that produce nanomaterials for aerospace and material engineering. The advisory board was employed to ensure quality of the content in the modules and to bring an industry perspective to assist in validating the modules and helping ensure that the content reflects current conditions of the use of nanomaterials. In addition, a survey was sent out to each NAC committee member to evaluate the quality of the content for continuous improvement. Table 1 shows a survey of the topic-specific modules developed for each course. Once the modules were constructed, they were implemented in existing courses at both institutions. Table 2 shows a summary implementation of introductory and advanced modules in existing engineering and technology courses at both institutions.

Pedagogical Considerations

Project personnel had the opportunity to design new teaching tools to reach a rapidly changing student population—one that is shaped by generation-specific experiences and expectations [39-42], and one that is increasingly diverse. Course modules were developed in light of research on these changes. Research shows that young workers are likely to feel pressure to act in ways that are unsafe or unethical [43]. Further research reveals that members of the current cohort of students, known as the millennial generation [39], have fewer resources (intellectual, psychological, social, and moral) to resist pressure to cut corners or to otherwise transgress safety and ethical norms than have members of previous generations [44]. For these reasons, some experts conclude, "In view of the [generational] differences, millennials face special challenges in the workplace" [45]. By 2025, millennials will make up the majority of the U.S. workforce [46].

Research gives some guidance in designing ethics and safety education for the current generation of students. Because of experience with information technologies, millennials typically have a significant skillsets with IT that they bring to the classroom and workplace. Millennials tend to have short attention spans, lack of experience in prioritizing, and are unpracticed in systematic or reflective thinking [47].

Table 1. List of Introductory and Advanced Modules

UT Tyler Courses that were taught	Texas State Courses that were taught	Introductory Modules	Advanced Modules
TECH 3304: Introduction to Nanotechnology Safety*	PHIL 1320: Society and Ethics	2A. Ethics of Science and Technology	2B. Applications of Nanotechnology
TECH 4314: Principles of Risk Management of Nanoscaled Materials*	TECH 4380: Industrial Safety	3A. Societal Impacts	3B. Assessing Nanotechnology: Health and Risk
	ENGR 2300: Materials Engineering	4A. Ethical Methods and Processes	4B. Sustainability Nanotechnology Development
	ENGR 2300: Materials Engineering	5A. Nanomaterials and Manufacturing	5B.Environmental Health and Risk
	MFGE/EE/TECH 4392: Microelectronics Manufacturing-I	8A. Military and National Security Implications	
	IE 4380: Industrial Safety	9A. Nanotechnology Issues in the Distant Future	
	MFGE 4367: Polymer Properties and Processes		3B. Assessing Nanotechnology: Health and Risk
	MFGE 4399: Polymer Nanocomposites		7B. Nanotechnology Risk Management

Note: ***All introduction and advanced modules were used for TECH 3303 AND TECH 4314**

These studies indicate that millennials are likely to resist, or even ignore, authoritarian or strongly hierarchical approaches to education. At the same time, millennials are found to respond well to clear structures and explicit support, including greater access to and interactions with instructors, to value experiential learning, and are motivated by a sense of purpose and meaning [48]. Howe and Strauss [48] describe the millennial students' personality traits as special, sheltered, confidant, team-oriented, conventional, pressured, and achieving.

Table 2. Infusion of Introduction and Advanced Modules in Existing Engineering and Technology

Introductory Modules	Advanced Modules
1A-What is Nanotechnology and Nanoethics?	1B-Overview of Occupational Health & Safety
2A-Ethics of Science and Technology	2B-Applications of Nanotechnology
3A-Societal Impacts	3B-Assessing Nanotechnology Health Risks
4A-Ethical Methods and Processes	4B-Sustainable Nanotechnology Development
5A-Nanomaterials and Manufacturing	5B-Environmental Risks Assessment
6A-Environmental Sustainability	6B-Ethical and Legal Aspects of Nanotechnology
7A-Nanotechnologyin Health and Medicine	7B-Developing a Risk Management Program
8A-Military and National Security Implications	8B-Presentations of papers or case studies
9A-NanotechnologyIssues in the Distant Future	9B-Hands-on training in safe handling practices of engineered nanoparticles (engineering, use of PPE).

A significant goal of this project was to encourage and mentor students from traditionally underrepresented groups to pursue careers in engineering. For this reason, the researchers integrated teaching techniques and strategies that research suggests are particularly helpful to such students. These include group projects, including group researched and written case-studies; guest speakers to discuss industry, government, and experiences from outside the academy; as well as other interactive learning approaches such as panel discussions, plant tours, and laboratory visits. Recent research indicates that the researchers could meet the anticipated shortfall in engineers in the U.S. if students who start as engineering students completed their degrees in engineering. A significant number of students, who begin university in engineering and STEM fields, complete degrees in non-scientific fields [49]. Among those who switch away from STEM are many women and underrepresented minorities. According to the studies, there are two primary causes for the move away from studying STEM. First, there can be a tension between the emphasis on individual success and on winning found in traditional STEM education and the values of many new students from underrepresented groups, which include a priority for group success and non-competitive advancement. [49, 50].

Second, traditional forms of education, quite common in contemporary STEM disciplines, that emphasize abstract principles, and in which teaching is often focused on the authority of the individual instructor, are not the most conducive for learning when a student best approaches problems through practical examples and concrete situations [51]. This learning style is best supported by using integrated lessons and by integrating simulations or projects that show the relationship of concepts to the real world. Furthermore, Camacho and Lord [50] demonstrated that Hispanic-Serving Institutions (HSIs) are very effective in nurturing and advancing Latino engineers to degree completion.

Assessment of Student Learning Outcomes

Assessment surveys were developed for the each module and a post-survey at the end of each course. The development of the module survey consisted of three- and four-point Likert scales, four questions for the Module Overall section, and three questions for the Module Materials section. There was a demographic section to fill out for the module and course surveys along with an open response question to gather strengths and weakness for each module and for the course. The open responses provided valuable descriptive information for continuous improvement for the modules. The purpose of the surveys was to obtain the students' perceptions of learning experiences for each module and for the entire course.

Collection of Data

Institutional Review Board approval at both institutions was obtained. In the fifteenth week of each semester course, the end-of-course surveys were disbursed to students to collect the summative data. Then, SPSS was used to generate and parse the quantitative data into frequencies for gender, age, ethnicity, major, classification, and student perception for each question for the module-specific and end-of-course surveys. An external evaluator conducted face-to-face focus groups with students to collect in-depth perceptions (qualitative data) of the students' learning experiences in a nanotechnology safety course.

Once the data were collected and a report developed, the project team met and read all of the data in the report, and considered feedback from the NAC, to make the necessary changes each semester to enhance the quality of the modules. The information from the reports was used to generate the official report to the project director at the Nation Science Foundation-Nanotechnology Undergraduate Division for each year of the study.

Demographic Data and Results of Student Perceptions

Demographic and student perceptions, based on the end-of-the-semester survey, are presented in this section. The data illustrated covered summer 2012, fall 2013, and spring 2014. Additional results (how easy were the modules to understand; overall quality of module materials; ability to provide real-world experience; and overall rating of the course), are also included.

Institution One

At Institution One, the instructor used all of the introductory and advanced modules for TECH 3304 and TECH 4313.

Demographics of Respondents: TECH 3304—Introduction to Nanotechnology Safety

Tables 3-6 illustrate the demographic results from TECH 3304—Introduction to Nanotechnology Safety (Summer II Session) at Institution One. There were 25 students enrolled for the course, with 15 students completing the survey. For Table 3, the majority of respondents for the summative course data were men. Table 4 illustrates that there were slightly more students who reported to be traditional students (18-23) than the other age groups for the course. Table 5 shows that TECH 3304 had more Caucasian students enrolled. Table 6 shows that there were more "other" students (business, management, and nursing majors) than industrial technology students enrolled for the course.

Table 3. Gender

Respondents by Gender	
Gender	No. of Respondents
Male	10
Female	5

Table 4. Age

Respondents by Age	
Age	No. of Respondents
18-23	6
24-30	4
31-35	3
36-40	2

Table 5. Ethnicity

Respondents by Ethnicity	
Ethnicity	No. of Respondents
Caucasian	12
African American	1
Asian Pacific	1
Other	1

Table 6. Major

Respondents by Major	
Major	No. of Respondents
Industrial Technology	4
Other	11

Student Perceptions: TECH 3304—Introduction to Nanotechnology Safety

Tables 7-10 summarize student perception results for the course, based on a three-point Likert scale. Table 7 illustrates that the students were ranked good to excellent for the modules easy to understand. Table 8 shows that the students found the quality of module materials to be excellent. Table 9 shows that the majority of the students found that the course modules provided information about and insights into real-world experience. The majority of the students in TECH 3304 rated the course excellent across the integration of the modules.

Table 7. How easy were the modules to understand?

Understandability of the Modules	
Likert Scale	No. of Respondents
Neutral	1
Good	5
Excellent	9

Table 8. Overall quality of module materials

Quality of Module Material	
Likert Scale	No. of Respondents
Neutral	1
Good	3
Excellent	11

Table 9. Ability to provide real-world experience

Real-World Application	
Likert Scale	No. of Respondents
Neutral	2
Good	5
Excellent	8

Table 10. Overall rating of the course

Course Rating	
Likert Scale	No. of Respondents
Neutral	2
Good	4
Excellent	9

Demographics: TECH 4313—Principles of Risk Management

Tables 11-14 show the demographic results from TECH 4313 – Principles of Risk Management for Nano Scaled Materials (Spring 2014) at Institution One. There were 33 students enrolled for the course, of which 21 completed the survey. Table 11 illustrates that the majority of respondents in TECH 4313 reported they were male. Table 12 shows that traditional-aged students, 18-23 years old, comprised the majority of respondents in the course. Table 13 shows that ethnicity, 57% of the students taking the survey identified themselves as Caucasian, the largest single ethnic group, while 14% identified as African American, 24% as Latino, and one student as Asian Pacific. Table 14 shows that the majority of respondents were industrial technology majors.

Table 11. Gender

Respondents by Gender	
Gender	No. of Respondents
Male	13
Female	8

Table 12. Age

Respondents by Age	
Age	No. of Respondents
18-23	15
24-30	5
36-40	1

Table 13. Ethnicity

Respondents by Ethnicity	
Ethnicity	No. of Respondents
Caucasian	12
African American	3
Latino/Hispanic	5
Asian Pacific	1

Table 14. Major

Respondents by Major	
Major	No. of Respondents
Industrial Technology	19
Other	2

Student Perceptions: TECH 4313—Principles of Risk Management

Tables 15-18 provide student perception results based on a four-point Likert scale. Table 15 shows that the majority of the students reported the modules as excellent for being easy to comprehend. Ninety percent ranked the modules good or excellent on ease of understanding. Table 16 shows that 95% of the students rated the quality of the module materials good to excellent. Table 17 reveals that the students' perception of the modules containing real-world experience examples/content was excellent. Ninety percent of students ranked the modules good or excellent on providing information about and insights into real-world experience. Table 18 shows that the majority of the students rated the course good to excellent, when the modules were integrated into the course.

Institution Two

Selected modules were used in four different engineering and technology courses and one philosophy course at Institution Two in the spring semester of 2014. The philosophy course is a required part of the core curriculum for all students, and the project modules were part of a special section with registration restricted to engineering and technology students.

Table 15. How easy were the modules to understand?

Understandability of Modules	
Likert Scale	No. of Respondents
Fair	1
Neutral	1
Good	8
Excellent	11

Table 16. Overall quality of module materials

Overall Module Quality	
Likert Scale	No. of Respondents
Neutral	1
Good	10
Excellent	10

Table 17. Ability to provide real-world experience

Real-World Application	
Likert Scale	No. of Respondents
Neutral	2
Good	7
Excellent	12

Table 18. Overall rating of the course

Overall Rating of Course	
Likert Scale	No. of Respondents
Neutral	1
Good	8
Excellent	12

Demographics

Tables 19-22 depict the demographic results from students who were enrolled in engineering and engineering technology courses and who experienced the integration of introduction and advanced nanotechnology safety modules at Institution Two. There were 500 students enrolled for the courses with the modules, of which 479 completed the survey.

Table 19 shows that, at Institution Two, the male student population was significantly larger than the female population with experience of the nanotechnology modules. Table 20 shows that the traditional-aged student population of 18-23 year-olds was the majority at Institution Two. Table 21 shows that 53% of students enrolled during the report period reported Caucasian as their ethnicity, while 47% self -reported as being “other”. Twenty-nine percent were Latino/Hispanic and 9.6% were African-American. Table 22 shows that, for majors, 52% of students enrolled in course sections covered by this report were engineering majors.

Table 19. Gender

Respondents by Gender	
Gender	No. of Respondents
Male	397
Female	82

Table 20. Age

Respondents by Age	
Age	No. of Respondents
18-23	379
24-30	80
31-35	13
36-40	5
40 and Above	2

Table 21. Ethnicity

Respondents by Ethnicity	
Ethnicity	No. of Respondents
Caucasian	255
African American	46
Latino/Hispanic	139
Asian Pacific	14
Other	25

Student Perceptions

Student perception is portrayed in Tables 23-25for the introductory and advanced nanotechnology safety modules integrated into engineering, engineering technology, and industrial technology at Institution Two. Student perceptions were based on a five-point Likert scale.

Table 22. Major

Major	No. Respondents
Engineering	250
Engineering Technology	72
Industrial Technology	19
Computer Science	2
Science (Physics/Chemistry/Bio/ Math)	21
Other	115

Table 23 reveals that the majority of student perceptions from the five-point Likert scale were good to excellent, indicating that the modules were written with sufficient detail and at the correct level to facilitate learning. Table 24 shows that the majority of student perceptions from Texas State University indicated good to excellent on the quality of module materials for the courses. Table 25 shows that a majority of student perceptions indicated "good" to "excellent" for the instructors, providing real-world experience illustrated in the modules. The majority of the students rated "good" to "excellent" on using the modules for the engineering and technology courses at Institution Two.

Discussion

The data presented cannot be generalized to other institutions that may offer nanotechnology safety. According to Tables 23-25, students at Texas State University and The University of Texas at Tyler were very satisfied with the nanotechnology safety modules integrated into the technology, engineering, and engineering technology programs.

Students were exposed to a different technology, rather than learning the typical content in technology, engineering, and engineering technology programs. Most importantly, students were able to establish a connection with nanotechnology and what types of technologies are associated with nanotechnology. Furthermore, students realized the importance and dangers of handling nanomaterials.

Conclusion

The project was successful for the first two years for both Institution One and Institution Two. The development and integration of nanotechnology safety modules were needed to laterally diffuse innovative materials into the mainstream of engineering, engineering technology, and industrial technology programs.

Table 23. How easy were the modules to understand?

Understandability of Modules					
	Poor	Fair	Neutral	Good	Excellent
ENGR 2300 MOD 2A&3A	0	1	5	19	4
ENGR 2300 MOD 1A&3A	2	1	6	18	5
IE 4380 MOD 3B	0	0	0	10	4
IE 4380 MOD 4B	0	1	0	9	4
IE 4380 MOD 6B	0	0	0	6	8
MFGE 2332 MOD 6A	0	0	3	19	4
MFGE 2332 MOD 9A	0	1	0	10	10
MFGE 2332 MOD 6A	0	0	3	7	9
MFGE 2332 MOD 9A	0	0	1	5	11
MFGE 4392 MOD 3B	0	0	1	4	3
MFGE 4392 MODULE 4B	0	0	0	2	2
PHIL 1320 MOD 2A	0	3	10	37	25
PHIL 1320 MOD 3A	0	2	6	32	19
PHIL 1320 MOD 4A	0	1	4	17	17
TECH 4380 MOD 3B	0	6	15	17	7
TECH 4380 MOD 4B	1	8	7	15	2
TECH 4380 MOD 6B	0	3	8	13	6

Note: 'A' modules=Introduction 'B' modules=Advanced

Table 24. Overall quality of module materials

Overall Quality of Modules					
	Poor	Fair	Neutral	Good	Excellent
ENGR 2300 MOD 2A&3A	0	0	1	22	6
ENGR 2300 MOD 1A&3A	1	2	10	14	5
IE 4380 MOD 3B	0	0	0	8	6
IE 4380 MOD 4B	0	0	1	8	5
IE 4380 MOD 6B	0	1	0	4	9
MFGE 2332 MOD 6A	0	0	2	16	8
MFGE 2332 MOD 9A	0	2	1	10	8
MFGE 2332 MOD 6A	0	0	3	10	6
MFGE 2332 MOD 9A	0	0	0	6	11
MFGE 4392 MOD 3B	0	0	0	5	3
MFGE 4392 MOD 4B	0	0	1	2	1
PHIL 1320 MOD 2A	0	1	7	33	34
PHIL 1320 MOD 3A	0	0	6	25	28
PHIL 1320 MOD 4A	0	0	5	15	19
TECH 4380 MOD 3B	2	5	14	16	8
TECH 4380 MOD 4B	0	5	10	15	3
TECH 4380 MOD 6B	0	3	10	13	4

Note: 'A' modules=Introduction 'B' modules=Advanced

Table 25. Ability to provide real-world experience

Real-World Applicability					
	Poor	Fair	Neutral	Good	Excellent
ENGR 2300 MOD 2A&3A	1	1	0	14	13
ENGR 2300 MOD 1A&3A	4	1	6	12	9
IE 4380 MODU 3B	0	0	0	8	6
IE 4380 MOD 4B	0	1	0	8	5
IE 4380 MODU 6B	0	0	0	5	9
MFGE 2332MOD 6A	0	1	3	14	8
MFGE 2332 MOD 9A	0	0	2	8	11
MFGE 2332 MOD 6A	0	0	1	8	10
MFGE 2332 MOD 9A	0	0	0	4	13
MFGE 4392 MOD 3B	0	0	1	5	2
MFGE 4392 MOD 4B	0	0	0	2	2
PHIL 1320 MOD 2A	0	0	6	24	45
PHIL 1320 MOD 3A	0	0	1	15	43
PHIL 1320 MOD 4A	0	0	2	7	30
TECH 4380 MOD 3B	0	10	9	16	10
TECH 4380 MOD 4B	2	4	6	17	4
TECH 4380 MOD 6B	1	2	5	13	9

Note: 'A' modules=Introduction 'B' modules=Advanced

Table 26. Overall rating of the course

Overall Rating of Course					
	Poor	Fair	Neutral	Good	Excellent
ENGR 2300 MOD 2A&3A	0	2	0	14	13
ENGR 2300 MOD 1A&3A	3	1	6	12	9
IE 4380 MOD 3B	0	1	0	9	4
IE 4380 MOD 4B	0	1	0	10	3
IE 4380 MOD 6B	0	1	0	6	7
MFGE 2332MOD 6A	0	1	3	17	5
MFGE 2332 MOD 9A	0	0	3	11	7
MFGE 2332 MOD 6A	0	0	2	10	7
MFGE 2332 MOD 9A	0	0	0	6	11
MFGE 4392 MOD 3B	0	0	2	4	2
MFGE 4392 MOD 4B	0	0	0	3	1
PHIL 1320 MOD 2A	0	2	6	37	30
PHIL 1320 MOD 3A	0	0	2	30	27
PHIL 1320 MOD 4A	0	0	5	15	19
TECH 4380 MOD 3B	1	7	16	12	9
TECH 4380 MOD 4B	1	6	8	16	2
TECH 4380 MOD 6B	0	4	9	12	5

Note: 'A' modules=Introduction 'B' modules=Advanced

The students' positive responses from the course surveys at both institutions may shed light on new knowledge that students were excited to receive. In addition, students may have welcomed new and innovative information provided through nanotechnology safety courses that have not been a part of traditional STEM courses. Integrated learning, repetition of material in varied contexts, and student enthusiasm and engagement are all indicators of better learning environments and are strongly correlated with better and long-term learning outcomes [51-54].

The efforts of the project team and NAC moved this project toward self-sustainability and made important contributions to strengthening engineering, engineering technology, and industrial technology programs at both institutions. The next step in self-sustainability for this program, to ensure its continued success, is to build a system for ongoing review and renewal, so that new information can be added to the modules. An additional challenge is better integrating the knowledge and insights of non-team members who infuse and teach modules in their courses at Institution Two. Perhaps the development of these modules can be a catalyst for faculty in other STEM areas to incorporate nanotechnology safety modules into their courses. Through this project, an educational effort of NSF, the project team has planted a seed to help with the cultivation of a nano-EHS workforce in the U.S. This is needed to support current and future endeavors for worker and public safety in the development and use of nanomaterials.

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INTEGRATION OF INDUSTRIAL PROJECTS INTO ENGINEERING EDUCATION

Yaomin Dong, Kettering University

Abstract

In this paper, the author presents an approach for integrating industrial projects into an engineering course. The goals of this approach were to bring the expertise of engineers in the field to the classroom and improve teaching and learning processes through real-life projects, where theories come to life through real problems and real data, and are taught by faculty partnered with industry experts. This approach was intended to make the course current, engaging, and motivating to the students, as well as to spark curiosity in students and demonstrate the usefulness of the theory being studied. The junior-level computer-aided engineering (CAE) course was used, where several automotive and industrial products were chosen for the homework assignment and term projects. To illustrate the use of the developed methodology, a case study of a windshield wiper system was provided. The students had to take on real challenges to solve engineering problems defined by the industry partners in the area of product design and analysis. Faculty and students toured industrial facilities to better understand the products and engineering issues, and engineers from the companies come to the university to deliver guest lectures. Structural analyses of the products were carried out using the finite element method (FEM). Improved designs were proposed by the students for material savings, cost reduction, and structural integrity. Such collaboration provides a valuable learning experience for the students and enhances their problem-solving skills. A course assessment was used to measure the effectiveness of the approach.

Introduction

Kettering University offers one of the largest co-operative educational programs in the U.S. The corporate sponsors of Kettering University's co-op students include the U.S. Army, General Motors, Ford, Fiat Chrysler Automobiles, as well as aircraft companies and their suppliers that included United Technology, Moog, IBM, Whirlpool, and over 600 other companies. These companies that sponsor Kettering University's co-op students represent a diverse cross-section of U.S. industries. The changes that have been taking place in these industries, including evolving industry needs and challenges, are immediately reflected in the classroom at Kettering, because the students bring valuable experience into classroom discussions after each alternating 3-month co-op term with the corporate sponsors. Kettering students were divided into two sections: A-Section and B-Section. Students rotated the academic and work terms every three months. For example, when the A-Section students were taking classes in school during the summer term, the B-Section students worked with the co-op employers. In the fall term, the B-Section students returned to school, and the A-Section students went work at the co-op companies. Moreover, many students conducted research on projects with the co-op sponsors when it was time for them to work on the senior theses. It is critical to bring real-life projects and industrial expertise to the classroom in order to stimulate student skills in creative thinking and problem solving, thereby achieving the desired educational outcomes of a balanced engineer. The main theme of this study was to develop a teaching model that integrates industrial projects into the curriculum.

The advantages of this teaching methodology are numerous, and affect the students, faculty, and even the industrial partners, as summarized below:

- Courses can truly reflect real-life engineering challenges.
- Courses can be interdisciplinary by engaging professors in academia and engineers in the field with unique expertise.
- Students are able to work with real issues of product design in the classroom.
- The problem-solving process allows students to see the professors as learners as well as teachers, and demonstrates that learning is a lifelong endeavor.
- The level of classroom discussion and interaction is improved when a co-instructor is there asking questions and asking for clarification. This interaction is beneficial for students, who might have trouble articulating the questions or may lack confidence to question the professor, who is seen as "the expert."
- Students have the opportunity to see what the jobs would be like after graduation.
- It is beneficial and inspiring for students to solve real engineering problems.
- Students have good models of teamwork when seeing professors collaborating with workplace engineers.
- Working with new people and learning more about different products is very stimulating for both faculty

members and students, and the enthusiasm makes the classes more interesting.
- It is beneficial for companies to have many different solutions to engineering problems at a very low cost or, ideally, no cost. Very often the students look at the projects from very different perspectives, which might lead to innovative solutions.
- Companies can find future recruits through this kind of interaction with students, and students also have the opportunity to see if the companies and products fit their future interests.

Certainly there are a lot of challenges in this teaching model, as noted here:
- The schedule of university classes may be very different from that of the current product development/ launch in the companies. Therefore, the conflict of priorities in educational institutes and industrial companies will have to be resolved and agreed upon.
- It would be difficult for all parties involved if the professors and engineers, administration, and management were not compatible. Faculty should never be forced into teaching with industrial collaboration.
- Preparation time for such endeavors can be limited and the logistics can be complex.

Computer-aided engineering, often referred to as CAE, is the use of computer technology in engineering tasks such as design, analysis, simulation, and manufacturing. This course was used as a template to illustrate this teaching methodology. The CAE course included, but was not limited to, the areas listed below:
- Computer-aided design (CAD), such as solid modeling and assembly modeling
- Stress analysis of components and assemblies using finite element analysis (FEA)
- Thermal and fluid-flow analyses using computational fluid dynamic (CFD)
- Process simulation in manufacturing, such as casting, molding, and forming
- Computer-aided manufacturing (CAM), such as graphic numerical control and SLA
- Optimization of products and/or processes

CAE, a junior-level mechanical engineering core course offered at Kettering University, is used to demonstrate the process of incorporating industrial projects. The course learning outcomes (CLO) of CAE are listed below. Upon completion of the CAE course students will be able to:
- Apply the fundamental principles of statics and mechanics of materials in engineering design.
- Apply modern analytical techniques to mechanical systems.
- Apply computational techniques to mechanical systems.
- Demonstrate effective communication skills through technical presentations and reports.

Current Course Situation

During the first three weeks of the 11-week CAE course at Kettering University, students work on solid modeling, sketching, assembly modeling, drafting, and advanced CAD topics, including parametric part design and inter-part assembly modeling. Figure 1 shows one such example for CAD; a valve assembly. Students are required to design each of the components, including the valve housing, shaft, retainer, plate, and crank. All parts are then placed in the assembly and mated properly. Advanced CAD techniques for this project include expressions and control parameters set at the assembly level so that the entire assembly can be adjusted automatically, based on the diameter of the main flow hole, the length of the crank, and the number of fasteners.

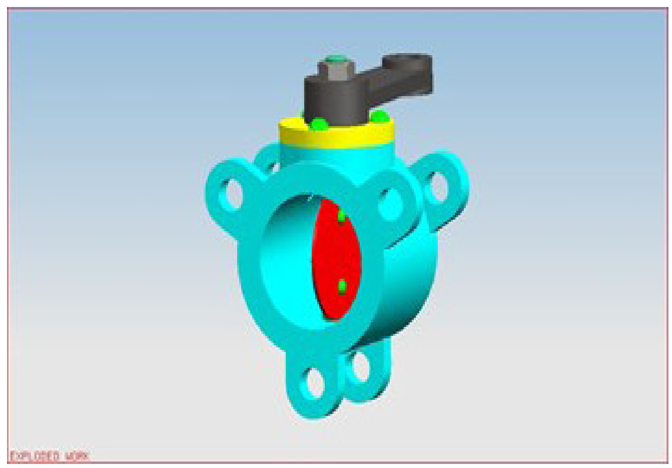

Figure 1. Valve Assembly

Over the course of the subsequent weeks, the main educational focus is on developing student skills in using FEA for the design of parts and assemblies. The fundamental techniques of FEA are introduced and applied to various structural components. Students perform analytical calculations based on traditional solid mechanics analytical approaches and compare the analytical solution to the numerical simulations developed in the FEA module of the software. Figure 2 shows the stress contour plot of a hook under a load. In this problem, one can see that an analytical solution can over-simplify the situation, when compared to results obtained from an FEA. Similar situations exist in the other assignments of the course; namely, the caster FEA of Figure 3 and the fixture FEA of Figure 4 assignments.

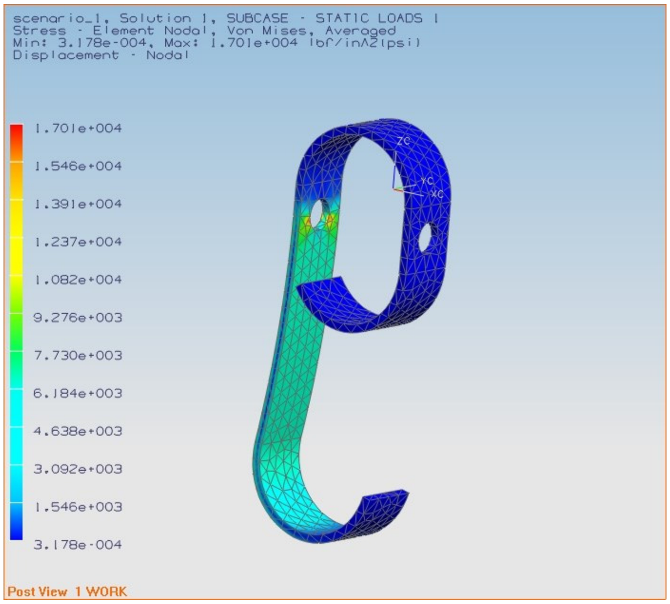

Figure 2. Finite Element Analysis of a Hook

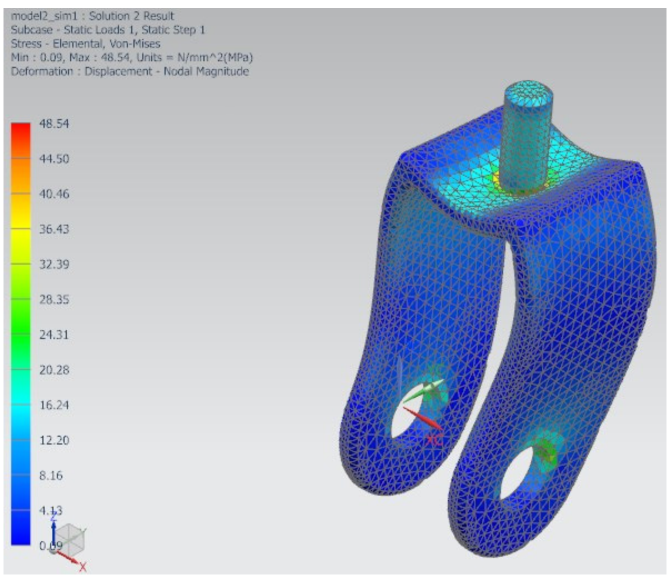

Figure 3. Finite Element Analysis of a Caster Frame

Proposed Course Outline

Figures 1-4 show that these assignments are traditional and general engineering problems that the students can solve by applying skills in engineering design and analysis. In order to make the course more current, engaging, and motivating to the students, as well as to spark curiosity in students and demonstrate the usefulness of the theory, there was a strong need to bring the real-life projects from the students' co-op work to the classroom. The following CAE course outline and template demonstrate this approach with great success. The process for teaching with industrial collaboration involves the following steps:

- Choose topic/theme
- Choose industrial partners
- Define course learning outcomes
- Outline matching/mapped activities
- Choose project with input from industrial partners
- Choose guest lecturers
- Provide field trip at industrial site
- Design assessments
- Construct timeline for development

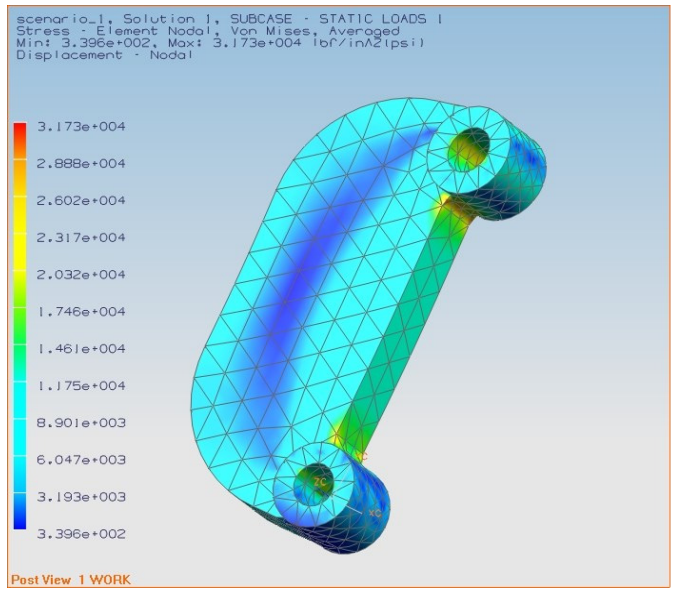

Figure 4. Finite Element Analysis of a Fixture

Table 1 shows the template of the CAE course outline, where the weekly topics are tabulated. There were two two-hour class periods per week for eleven weeks. This template can be modified for other courses and project types.

Best Practices

There are many challenges in planning this kind of team teaching. Some of the best practices are summarized below:

- Do not underestimate time requirements.
- There will always be "fires," so plan for them.
- Keep open communication; when in doubt, ask for approval from management and administration.
- Remember that the challenges that the students encounter are not unlike situations that will be found in industry—do not underestimate the value of this learning.
- Make the development of the team a top priority. Don't just assume that the team will work well together.

- Set clear goals for the team that all members agree upon, and then ensure that its activities lead to those goals.
- Communicate clearly and honestly to survive and grow stronger from conflict.
- Honor individual and team success through administrative support.
- Assume responsibility for assigned roles.
- Be prepared for team discussions and work.

Table 1. Course Template of Teaching with Industry Experts

Wk	First class period	Second class period
1	Introduction to class /Selection of project teams	Overview of industrial project with engineers/ presentation
2	Lecture 1, assignment 1	Lecture 2, assignment 2
3	Guest lecture-topic 1	Progress report/pres. on projects
4	Lecture 3, assignment 3	Lecture 4, assignment 4
5	Lecture 5, assignment 5	Assessment/exam 1
6	Guest lecture-topic 2	Lecture 6, assignment 6
7	Lecture 7, assignment 7	Lecture 8, assignment 8
8	Lecture 9, assignment 9	Progress report/pres. on projects
9	Progress Review	Assessment/exam2
10	Lecture 10, assignment 10	Lab, Q and A
11	Lecture 11, assignment 11	Lecture 12, assignment 12
Final	Final presentation	Final exam

Guidelines

Guidelines for both the faculty and guest lecturers are summarized below:

- Provide time estimates and orientation for guest lecturers—be a coach.
- Attend all class sessions with guest lecturers.
- Help the engineers to understand how your students learn best.
- Be approachable and seek regular feedback from students.
- Communicate the plan of delivering the lectures.

Suggested Activities

The following activities are very helpful for both the faculty and guest lecturer:

- Discuss course topics or pre-reading.
- Visit industrial sites and meet engineers in the field as much as possible.
- Present research papers.
- Have students set the performance criteria and expectations for grading.
- Present projects.

Checklist

The following issues should be discussed and decided upon before beginning in order to prevent conflict later and make the team more efficient from the start:

- What is the scope of the industrial project integration?
- What are the IT requirements?
- What is the approval timeline?
- Is information obtainable in a timely manner?
- Is there a confidentiality issue with the industrial projects?
- Is it an appropriate level of challenge, based on the background of students in class?
- What materials, books, and supplies are needed?
- Who provides what, how to get it?
- Who should teach what?
- What content should be divided?
- What content should be taught jointly?
- How would the students' work be graded?
- Who grades which papers?
- What is the grading system?

Case Study: Windshield Wiper System

In order to demonstrate the team teaching approach, an automotive windshield wiper system design and analysis project was chosen as a case study. Automotive windshield wiper systems, in conjunction with washer systems, are used in vehicles to remove contaminants such as rain, sleet, snow, and dirt from the windshield. Figure 5 shows that a typical wiper system consists of an electric motor, a linkage to transform the rotational motion from the motor to oscillatory motion, and a pair of wiper arms and blades. The areas of the windshield that must be wiped by the wiper system are mandated by federal motor vehicle safety standards, FMVSS 104 [1].

The new CAE project was the design and engineering analysis of automotive windshield wiper systems. Students designed the main components using CAD software. For critical components, such as wiper arm, pivot shaft, rocker arm, etc., the engineering analysis would be performed using FEM to meet the product specifications. Students presented the projects and wrote technical reports at the end of the term. The following steps demonstrate the process of this new teaching and learning approach.

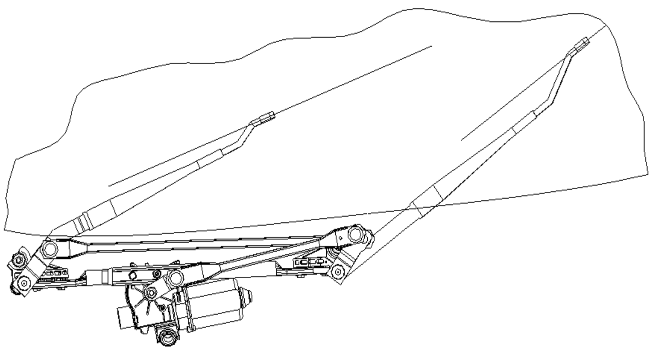

Figure 5. A Typical Wiper System

Step 1. Definition of Student Learning Outcomes by Faculty and Engineers

It is critically important to define, design, and align the class activities with the students' learning outcomes. For this course, the students' learning outcomes included the following items:

- Improve problem-solving skills in real-life projects.
- Apply knowledge learned on engineering mechanics.
- Apply engineering principles to reduce cost in materials and manufacturing, and the mass of products.
- Apply skills in computer-aided engineering (CAE).
- Develop environmentally friendly products.

Step 2. Project Orientation by Engineers

For this study, faculty teamed up with the automotive windshield wiper system expert to redesign the wiper products that have snow load failures. Figure 6 shows a typical wiper-arm-and-blade structure. Figure 7 shows how the wiper arm and the lever are mounted on the pivot shaft that is located in the pivot housing assembly. The pivot housing assembly includes grommet, retainer, washer, O-ring, bearings, spring washers, pivot shaft, lever, and ball stud.

Step 3. Design and Analysis of Windshield Wiper Systems by Students Supervised Jointly by Faculty and Engineers

Supervised jointly by the faculty members and engineers from industry, different project teams performed their own designs approved by the teaching team. Figure 8 shows a depiction of the stress analysis of the wiper arm [2, 3].

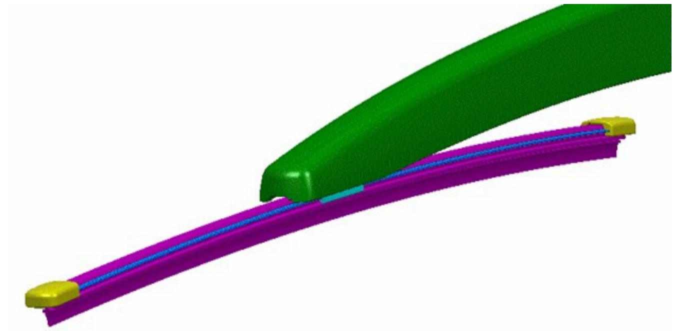

Figure 6. Wiper Arm and Blade Assembly

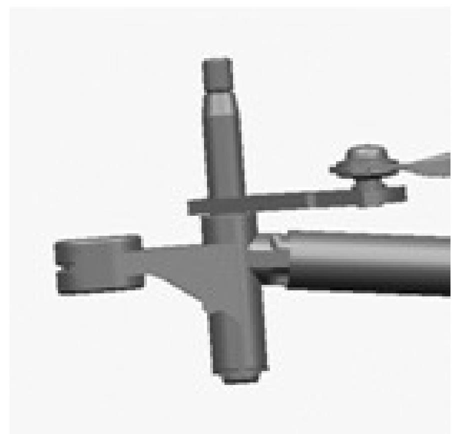

Figure 7. Frame and Pivot Housing Assembly

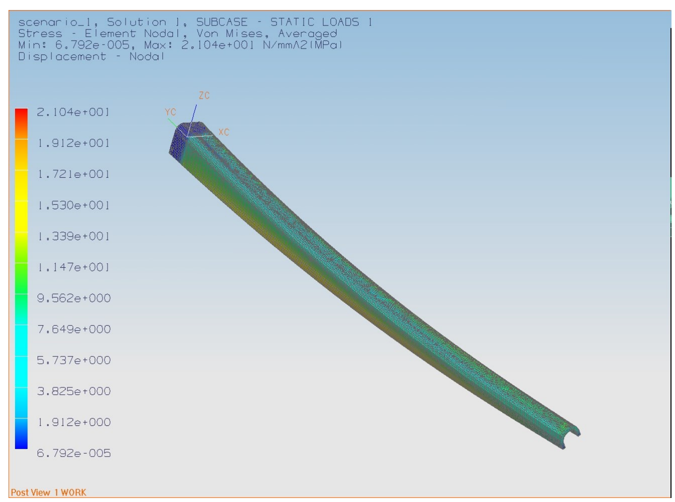

Figure 8. Wiper Arm Stress Distribution by FEA

The pivot shaft is the most critical component in the pivot -shaft assembly, because the wiper-arm-and-blade assembly is mounted on the pivot shaft, and the lever is connected in the middle. If the pivot shaft fails, the whole wiper system will lose its performance, even its function. Figure 9 shows the stress and displacement results. Using the rolled steel material properties, the wiper arm is safe in this design.

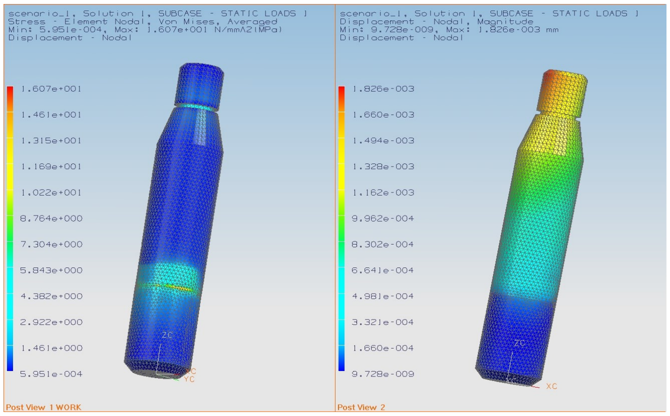

Figure 9. Pivot Shaft Stress and Deformation by FEA

Step 4. Solutions for Overload Problems by Students Supervised Jointly by Faculty and Engineers

Figure 10 shows how snow and ice often build up on windshields in winter. The snow/ice stack can literally block the wiper arms and blades and, therefore, the wiper system load will increase significantly. Such an excessive load, often referred to as snow load, will cause either fatigue or catastrophic system failure. Figure 10 shows a broken rocker arm illustrating such a failure.

Figure 10. Windshield Wiper under Snow Load Breaking a Rocker Arm

Figure 11 depicts a proposed solution [2-7], based on the research of the current author, who is also the faculty instructor of this course. In this illustration, the hatched area represents a snow/ice pack above the cowl screen, which restricts the normal motion of the system. Once the arms have contacted the restriction, the loading in the system increases as the motor torque approaches the motor's stall torque. However, once the critical load is reached in the connecting rod, the rod will buckle, limiting any further increase in system loading, thereby allowing the crank to rotate through the reversal position. In the illustration, the connecting rod is shown in the post-buckled configuration. Figure 12 depicts a connecting rod of length L, the cross-sectional area, A, and cross-section moment-of-inertia I. The elastic modulus of the material is denoted as "E". The ends of the rod are free to rotate, due to the socket-ball joints. The external compressive load, P, is applied at the centroid of the cross section.

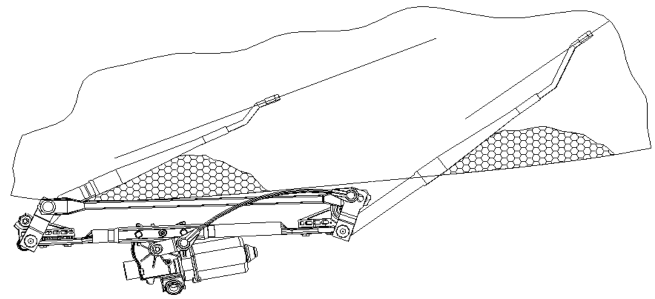

Figure 11. Windshield Wipers with a Flexible Linkage

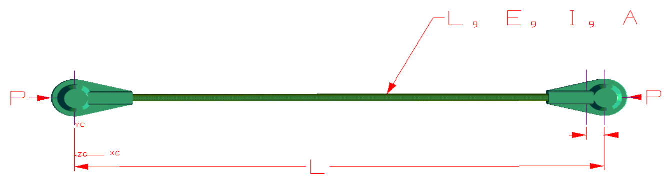

Figure 12. A Flexible Linkage

As the load is increased, assuming that the elastic limit of the material is not reached, a critical point is encountered at which the rod deforms laterally. In this configuration, the rod supports the load via bending. The applied load at which this transition occurs is referred to as the "critical load" or "Pcr." Pcr can be determined by "I" for a given cross section, L, and Young's modulus, E, of the material, as given by Equation (1) [8]:

$$P_{cr} = \frac{\pi^2 \cdot EI}{L^2} \tag{1}$$

The wiper linkage mechanism can, therefore, be designed with the flexible connecting rod. The spherical sockets at both ends of the linkage are over-molded plastic parts to provide for ball-socket joints [2, 5, 7]. The composite material is selected per the following specifications:

- Resin specification: thermoset polyester (21% by weight)
- Fiber specification: 113 yield E-glass roving (75% by weight)
- Filler content (4% by weight)

The monotonic mechanical properties of the materials are listed here:

- Elastic modulus: 43 GPa (6.2 Mpsi)
- Ultimate strength: 1140 MPa (165 ksi)
- Strain at fracture: 2.6%
- Specific gravity: 1.92

The flexible connecting rod undergoes a maximum tensile load of 1000N at motor stall. Figure 13 shows how the stress and deformation are calculated by the students using FEA.

Assessment

To measure the technical role of students as "collaborators" in the team projects, the assessment method of direct observation was used and three key performance indicators were selected from a published list of attributes [9]. These attributes were: 1) respecting individuals with diverse backgrounds, perspectives, and skills important to the efforts; 2) valuing roles, accepting role assignments, and supporting others in the roles; and, 3) contributing to the effective cooperation of the team in its development of consensus goals and procedures. These attributes were mapped to corresponding rows in an analytical teamwork rubric. Table 2 shows the adapted, modified rubric.

Table 2. Key Performance Indicator Rubric

Key Performance Indicator		Beginning	Developing	Accomplished	Exemplary
	Listens to other teammates	Always talking - never allows anyone else to speak	Usually doing most of the talking - rarely allows others to speak	Listens but sometimes talks too much	Listens and speaks a fair amount
	Fulfils team roles/duties	Does not perform any duties of assigned team role	Perform very few duties	Perform nearly all duties	Performs all duties of assigned team role
	Cooperate with teammates	Usually argues with teammates	Sometimes argues	Rarely argues	Never argues with teammates

Table 3. ABET Assessment Rubric 2016

ABET Criteria	Exceeds Requirement	Meets Requirement	Partially Meets Requirement	Does not Meet Requirement	Not Applicable
(a) An ability to apply knowledge of math, science and engineering	89%	11%			
(b) An ability to design and conduct experiments, as well as to analyze and interpret data	89%	11%			
(c) An ability to design a system, component or process to meet desired needs within realistic constraints such as; economic environmental, social, political, ethical, manufacturability or sustainability					NA
(d) An ability to function on multidiscipline teams					NA
(e) An ability to identify, formulate, and solve engineering problems	100%				
(f) An understanding of professional and ethical responsibility					NA
(g) An ability to communicate effectively	100%				
(h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and social context					NA
(i) A recognition of the need for, and an ability to engage in lifelong learning					NA
(j) A knowledge of contemporary issues					NA
(k) An ability to use the techniques, skills and modern engineering tools necessary for engineering practice	89%	11%			

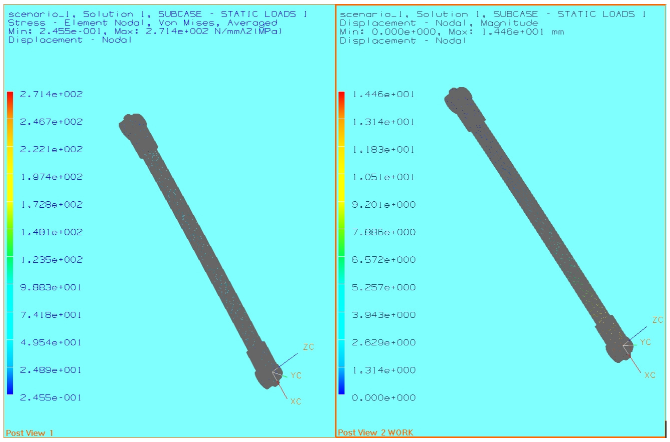

Figure 13. Linkage Stress and Deformation by FEA

Based on direct assessment of the students, over 80% of the class measured "Exemplary" in all three key performance indicators selected for the technical role of Collaborator. The other 20% of the class measured Exemplary in two key performance indicators, and Accomplished in one key performance indicator. When this was compared to the program target of all graduating students measuring Accomplished, this signified that it was clear that pedagogical interventions, such as integrating industrial projects into engineering courses, can indeed enhance student movement toward achieving educational objectives and outcomes. The comments of the students on the course evaluations suggested that such innovative classroom techniques may also have increased their enthusiasm and engagement.

ABET criteria were used to assess the CAE course learning outcomes (CLO). The five CLOs were mapped to the ABET criteria (a, b, e, g, k). Table 3 shows the results of spring 2016 assessment results, after integrating industrial projects with the teaching approach presented here. All students met or exceeded requirements in the ABET assessment rubric, which was a huge improvement compared to the assessment results of 2014 (see Table 4) before this new course portfolio was used. In 2014, 10%-20% scored in "Partially Meets Requirements."

Table 4. ABET Assessment Rubric 2014

ABET Criteria	Exceeds Requirement	Meets Requirement	Partially Meets Requirement	Does not Meet Requirement	Not Applicable
(l) An ability to apply knowledge of math, science and engineering	70%	10%	20%		
(m) An ability to design and conduct experiments, as well as to analyze and interpret data	70%	10%	20%		
(n) An ability to design a system, component or process to meet desired needs within realistic constraints such as; economic environmental, social, political, ethical, manufacturability or sustainability					NA
(o) An ability to function on multidiscipline teams					NA
(p) An ability to identify, formulate, and solve engineering problems	80%	10%	10%		
(q) An understanding of professional and ethical responsibility					NA
(r) An ability to communicate effectively	70%	10%	20%		
(s) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and social context					NA
(t) A recognition of the need for, and an ability to engage in lifelong learning					NA
(u) A knowledge of contemporary issues					NA
(v) An ability to use the techniques, skills and modern engineering tools necessary for engineering practice	70%	10%	20%		

Conclusions

A teaching strategy to integrate industrial projects into the classroom was proposed. To facilitate the development of this type of collaborative learning, a template for such a teaching model was provided. Using this template, a methodology that included best practices, guidelines, and activities was developed, which could be used by faculty to more easily integrate practice into the classroom. A checklist for selecting appropriate industrial projects with the collaborating partners was also included. To illustrate the use of this approach, a case study of a course partnership between industrial experts and faculty is provided here. This case study involved an automotive wiper system design. A typical failure of wiper systems is caused by snow load. Through the novel use of the composite material properties, the wiper system is protected from loading extremes, and its durability is enhanced. The author has been involved in similar teaching models with other such classes before, and this work summarizes valuable lessons learned. Such a collaborative course teaching approach not only solves an industrial problem, but also stimulates critical thinking and teamwork between faculty, field engineers, and students.

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Biography

YAOMIN DONG is an associate professor of Mechanical Engineering at Kettering University. He earned his MS and PhD (Mechanical Engineering) degrees from the University of Kentucky. His interests include solid mechanics, computer-aided engineering, finite-element analysis, and engineering materials. Dr. Dong may be reached at ydongl@kettering.edu

PROCESS SIMULATIONS AS A BEST PRACTICE IN LEAN TRAINING

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Abstract

Researchers report failure rates for lean implementations of 50% and higher. Although the causes of failure remain a topic of debate, most discussions center on lean management and not the tools, techniques, or methods of lean. Scholars highlight inadequate appropriation of resources, intolerance for failure, top-down process improvement, poor organizational culture, and/or low trust, as causes of lean failures. To enhance lean success, the author proposes using process simulations to teach lean tools and methods, along with the lean management principles that undergird successful lean implementations. By using process simulations, participants at all organizational levels can be frustrated, learn, try, fail, and try again in an environment that is fun, low risk, and related to, but not the actual, work environment. Participants gain first-hand experience of trusting each other to recognize problems, develop solutions, and implement changes in order to maintain the continuous improvement mindset required by lean.

Introduction

Lean and its associated tool Six Sigma have documented success in efficiency gains and cost reduction in industry [1, 2]. Lean is generally recognized as the method used to create the platform from which Six Sigma can proceed. Yet, despite the documented effectiveness of lean, most companies fail to realize expected gains [1, 2]. Sadly, the popular media report failure rates for lean implementations of 50% and higher [3, 4]. Given the cost of implementing lean—including staff training, process changes, tools, and in some cases software—low rates of implementation success are unacceptable [1].

While the cause of lean failures remains a topic of debate, most discussions center on lean management and not the tools, techniques, or methods of lean. Scholars highlight inadequate appropriation of resources, low trust, top-down process improvement, poor organizational culture, and/or intolerance of failure, as causes of lean failures [1, 2, 5-7]. That is, rather than failing to teach staff how to perform a value-stream analysis or interpret a control chart, two commonly used lean tools, organizations fail to create a work context consistent with lean principles, such as respect for people and continuous improvement [8].

The Importance of Work Context

Context exerts a powerful influence on human behavior across phenomena. In the context of work, research on the job characteristics model [9, 10] highlights the features of autonomy, feedback, using a variety skills and talents at work, doing work that is valued by others, and completing an entire and identifiable piece of work as comprising the important immediate context within which people work. These features consistently demonstrate influence on employee motivation and performance [11-13]. Other scholarly domains have also noted the influence of context on behavior. Social activists and scholars investigating criminal recidivism support the importance of context in changing ex-offenders' behavior [14-16]. Pettigrew [17] also supports the role of context, when seeking to reduce prejudice and discriminatory behavior. Clearly, behavior is not entirely driven by the habits and choices of the individual, but also, importantly, by the context in which the individual is placed.

Returning to the work context, consider Toyota Motor Corporation, an internationally recognized leader in lean manufacturing [7]. Productivity rates of workers in U.S.-based Toyota automotive plants exceed those of workers in U.S.-owned automotive plants but are comparable to their Japanese counterparts working in Toyota plants in Japan [18]. Such evidence suggests that the difference in productivity is due to work context (i.e., a world-class, lean manufacturing environment) and not inherent differences between workers in different countries. To paraphrase Deming [8], the people are not the problem; it is the context in which they work.

The Challenge for Lean

How is it, then, that lean tools and methods can be effectively taught without also producing a work context that supports the principles on which they are predicated? Lean scholars routinely emphasize the importance of leadership to enable the transformation of a traditional workplace to a lean workplace [8]. Therefore, many lean training programs also highlight the importance of effective leadership. Barling [19] makes the case that leadership skills can be taught effectively—although not all training programs are equally effective and not all students are equally likely to act on their training. However, Barnett and Ceci [20] note that effective transfer of training to the relevant work context is difficult and subject to various factors being in place (e.g., type of practice sessions used during training, compared to how learning is applied on the job). Even if effective leadership skills are taught, scholars are indicating that getting managers to transfer their new knowledge to the workplace is a challenge.

Upper-level managers are least likely to benefit from leadership training [19], thereby creating a problem for lean transformation. Upper-level management has the power to enforce new behaviors; yet, if they do not adopt or fully recognize the importance of the new behaviors, leaders in upper-level management are unlikely to have direct reports who adopt those behaviors. Unfortunately for lean, it is the lower-level managers who oversee what happens among workers. A failure of upper management to "talk the talk and walk the walk" is viewed by lower management as giving lip service to the importance of lean, while not adapting their behaviors to support respect for people and continuous improvement. Workers perceive a disconnect between upper management's words and actions and, as a result, wait out what they perceive to be the latest management fad, yielding a lean implementation failure.

Yet another problem is likely to enter the mix. During lean training, lean tools and methods are often viewed as detailed and complex [7] and run counter to the common sense of traditional business methods [8, 21]. People learning lean are then in a novel environment in which their first instinct is likely to be wrong. In such circumstances, people are likely to focus on details (e.g., what shape represents a person in a value stream chart?) and may not give appropriate weight to general principles such as respect for people and continuous improvement [22], contributing to a lean implementation failure.

A final problem has to do with the perceived difference between workers and management. Evidence suggests that a perceived social difference develops early in a management career. One of the most difficult steps for a worker to take is navigating promotion from worker to front-line supervisor [19]. A newly promoted front-line supervisor is in charge of people who were recently peers, and with whom the supervisor identifies and may consider to be friends. However, the demands of the new role require the supervisor to respond to discipline problems and failure to meet goals, and customer complaints causing cognitive dissonance between the supervisor's feelings and role-required behaviors toward employees [23]. In response to cognitive dissonance, new front-line supervisors, who stay in the role, will likely align their feelings and behavior, creating distance between themselves and their employees. As distance develops, front-line supervisors become more aligned with management's views and less likely to identify with employees.

The distance may have pernicious social effects. Moore and Gino [24] document that perceived power differentials can lead to unethical managerial behavior, potentially legitimizing the perceived social distance between management and workers. Tellingly, Grant [25] wrote that transformational leaders may be more effective when "they interact with the beneficiaries of their work." Indeed, unions that represent the needs of workers are often viewed as having goals counter to those of management. Perhaps as a result of the preference for the more powerful role of upper management, scholars acknowledge that managers are disproportionately represented in the research literature relative to workers [26]. To the extent that perceived social distance exists between workers and management, workers and management are less likely to work together effectively [23]. Workers may not be given the latitude to create and implement the most effective lean solutions; worse, lean training may not include workers at all [7]. Front-line supervisors are then put in the position of being lean trainers for their employees. If the supervisor fails or even fumbles, workers are unlikely to perceive that the supervisor has the competence to implement lean. Lacking competence, workers are unlikely to trust the supervisor as they embark on a transformation of their workplace [27], yielding a lean failure.

In sum, lean implementation is a thorny problem. Upper-level managers are likely to fail to enact new leadership behaviors to support respect for people and continuous improvement, even if they are presented during training. Furthermore, any lean training will be perceived as novel and, therefore, subject to judgment errors and preserving the details, at the expense of losing sight of the larger picture. Finally, social distance between workers and management may prevent effective implementation of lean.

The Potential of Process Simulations

An effective solution to the aforementioned challenges must

- Teach leadership behaviors needed to support lean principles of respect for people and continuous improvement, as well as lean tools and methods.
- Help upper management engage in behaviors to support lean principles.
- Provide a learning context in which lean tools and methods are used to support lean principles.
- Reduce the perceived distance between workers and management.

To achieve these goals, the author proposes using process simulations to teach lean principles along with lean tools. The term simulation has been used in the literature to describe computer simulations, paper-based active learning exercises, single- or multi-player games, and other types of active learning methods [28]. However, the key component that must exist for any type of simulation to be effective is learner engagement [28, 29].

Process simulations engage learners because they use participants to enact steps of a process, or job, required to deliver value to customers. To be effective lean teaching tools, they are initially designed to demonstrate process failures, create conflict among participants, and deliver poor customer service. As participants perform their jobs and complete the process, they notice inefficiencies in the sequencing of jobs, how the simulation rules create conflict, and how job descriptions enable inefficient performance. Therefore, process simulations effectively set up a context in which lean tools and methods can effectively transform a workplace, when lean principles are the foundation upon which the transformation is placed. That is, the jobs, sequencing of them, and simulation rules are the focus of improvement efforts, because respect for people and continuous improvement undergird those improvements.

Consider a patient intake process simulation. Suppose the process simulation has the job “Admissions Clerk”. To complete this job, a participant must compute the age of a patient using the patient’s date of birth, without support from tools such as a calculator. Such a task is likely to be error prone, as it requires arithmetic and, perhaps, attention to the month of birth and the current month of the year. However, having a patient’s age correct is important to roles played by other participants later in the simulation (e.g., the “Nurse”). Solutions that feature respect for people and continuous improvement will not blame the person who is the “Admissions Clerk” for errors during the simulation. Rather, participants would be encouraged to solve the process problem by providing a calculator or other tool of standard work rather than a solution focused on the person—such as teaching the person to subtract dates without assistance under time pressure. To emphasize continuous improvement, participants would applaud the cases where simple subtraction of the year of birth from the current year is correct and develop new solutions to address month-of-year issues (perhaps a note in standard work about how months should be used, if at all, to calculate age).

Note that process simulations are not role-play exercises. Role-play exercises typically provide participants a description of a character to play and an issue to resolve with one or more participants playing different roles [29]. Role-plays are not typically scripted. Trainers rely on the participants’ prior learning and ability to improvise, as they interact with other participants. Students are expected to apply learning to resolve the problem by spontaneously acting out their roles in a way that is consistent with information from the training event.

Process simulations, on the other hand, require participants to perform work-related tasks in a defined sequence that comprises a value stream, albeit a poorly designed one at the outset. Participants may complete paperwork, deliver work in process to other participants, or do other tasks that constitute value for customers of the simulated process. Various rules and requirements are embedded into each job. These rules, as well as typical lean concepts, such as batching, work layout, or producing value at the pace of the customer, become the focus of a transformational process redesign that uses lean tools and is based on lean principles. The participants’ jobs are sufficiently explained so that they can perform their part of the simulation without feeling the pressure to improvise in the way that role-playing typically requires (some room for improvement in their job descriptions is built in to introduce the lean concept of standard work).

In addition, a process simulation is related to, but not a replica of, the actual work of the participants. That is, the process simulation should be close enough to the participants’ work in order to seem relevant (i.e., face valid), but not so close to the actual work that they analyze how accurately the simulation matches their particular work environment. The simulation must not lead participants to focus on the fidelity of the simulation compared to their real work environment or tools. If it does, then participants will likely focus on details—why isn’t this the same invoice that the company uses?—and miss the importance of the lean principles of respect for people and continuous improvement [22].

Another benefit of the process simulation’s low-risk environment is that it can be used to reduce perceived social distance. The process simulation is clearly contrived. It does not emulate the actual workplace, the process does not recreate an existing process, and people are assigned jobs in the simulation that do not align with their actual jobs. This approach enables people at different organizational levels to interact in the simulation in ways that they do not interact during their everyday work. When people who may not be familiar with each other are put in the position of working together in the process simulation, perceived social differences between them are likely to be reduced [17]. The process simulation can then encourage trust to develop among workers, as well as between workers and managers, as required to implement lean successfully.

By assuming different jobs, each participant develops a deep understanding of one part of the process' initial design, or current state, to use lean jargon. Therefore, each participant can provide a unique contribution when documenting the process. Trainers then use this knowledge to discuss effective team construction. Hackman [30] notes that team composition has a significant impact on team performance. Team members need to have task-relevant knowledge that has minimal overlap with other team members. If team members' roles largely overlap, social loafing is likely to occur [31] or one team member may be deferred to, thereby reducing the team's ability to engage all members in documenting and redesigning the process [2, 30].

To enhance the transfer of lean principles, participants must be shown during training that all team members are needed to create a lean transformation. Womack and Jones [2] note that lean teams often fail to include the people actually doing the work, without whom some steps that create value and waste are likely to be missed or hidden, leading to lean implementation failure. Trainers can use process simulations to point out details of the process that would be lost if a given participant did not contribute details about the assigned job, providing a segue into the importance of the lean concept of Gemba or "going to the source." To the extent the simulation is engaging for all members, participants witness first-hand that others want to do their jobs well [7, 10]. Even in the simulation's contrived context, they want to deliver value to customers. As a result, all participants demonstrate that they have the knowledge and motivation to do their jobs, make meaningful improvements to their jobs, and focus on the customer, which in turn enhance perceptions of trustworthiness among participants [27].

Finally, Clark [28] noted that fun training is more effective that boring training. Even if the training is engaging, adding the element of fun can further aid learning. Good simulations make members feel like they are playing a game, and often rate it as being enjoyable [29]. Beyond learning, training that incorporates fun will be more easily sold to, accepted by, and enable transformation of an organization and its members. Process simulations build on the fun characteristics of simulations, producing a learning environment that aids learning and transfer of training. A problem remains: will upper-level managers act on their training and support lean principles? Research clearly shows that upper management struggles to release control or adapt existing control mechanisms to support lean implementations [6, 32]. However, Deming [8] referred to an inverted view of management, where management's role is to make workers' jobs easier. Importantly, lean success stories consistently highlight that workers and their immediate supervisors are empowered to make changes consistent with lean, missteps are tolerated, and reward systems are changed to incentivize behaviors that support lean transformation and deliver customer value [33]. Indeed, traditional management practices must change to enable successful lean implementation.

Although no outcome is assured, process simulations can provide an experience that enables workers and management to develop trust in each other. Process simulations show that participants can be trusted to identify problems and create processes that are lean and deliver value. By participating in a process simulation with workers, front-line supervisors and upper management can directly observe that process problems are detected by workers and that workers cooperate with managers to address those problems, even while having fun. Process simulations are not guaranteed to influence upper management, but they provide a compelling platform to create conditions under which upper management can be transformed along with processes that deliver value to customers.

Exemplar: LeanOhio Boot Camp

LeanOhio Boot Camp [34] provides an excellent example of the use of process simulations. Lean Ohio Boot Camp's purpose is to introduce government staff to lean. Since 2011, initiatives lead by LeanOhio trainees have saved millions of dollars for the state of Ohio. Notably on the first day of training, participants map the current state of a process simulation. The process simulation has nine roles designed to deliver grant approval from a fictional Department of Prevention. Typically, participants document 50 or more steps as the current state of the process simulation of which only three or so are value added.

Trainers then demonstrate that the people doing the jobs are not at fault. Rather, the role descriptions are not focused on value, and the process by which the roles interact is not focused on value. As participants are guided to focus on the value-added steps, they create a future state in which the convoluted steps of the process are effectively replaced with just three steps. The comparison of the current and future states routinely create an "A-ha!" moment for participants to anticipate the types of transformational change that could be realized when they return to their workplace to apply lean tools and methods.

Conclusion

The argument presented here indicates that process simulations have the potential to reduce the likelihood of lean implementation failure. By positioning process simulations at the outset of introducing lean into a workplace, process simulations can teach lean tools, while using lean principles as the foundation of training. Process simulations directly teach lean tools, as well as lean principles, enabling participants to engage lean principles as they use lean tools to transform work. At the outset of implementing lean, training must incorporate interactions that reduce social distance and build trust between management and workers so that managers are willing to empower workers.

Future Research Directions

The author builds a case that process simulations are likely to enhance lean implementations. Future research should focus on the amount of process simulation required in lean training, the optimal mix of workers, participation needs of front-line managers and upper management, and how to balance direct teaching of lean tools compared to lean management principles to increase lean implementation success. Such information would enable trainers and organizational leaders to enhance the introduction and potential for transformation of lean workplaces.

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Biography

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A COMPARATIVE EVALUATION OF PRINTED CIRCUIT BOARD LAYOUT SOFTWARE

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Abstract

Printed circuit board (PCB) layout is a critical function in the development of successful electronic circuitry. Numerous tools are available to do PCB layout, with costs varying from free to quite expensive, and a wide range of technical capabilities. Some tools are part of a circuit simulation package, while others are standalone. In this paper, the authors focus on software tools that have free versions available. First, a brief synopsis of the capabilities of six packages is presented, followed by a more in-depth treatment of three of them, including screenshots of PCBs laid out and using them. The three software packages described in detail are Ultiboard by National Instruments, PCB Artist by Advanced Circuits, and Eagle by Cadsoft USA.

Introduction

The purpose of this evaluation was to determine which software packages would be suitable for educational use, in this case at Purdue University, and which would be appropriate for professional use at small businesses. With so many options available, this evaluation will help sift through three PCB layout tools to clarify their strengths and weaknesses. To ensure that each of these PCB layout programs were evaluated fairly, the exact same circuit was designed in each program. Similar tools within each software package were used to see which programs made the process easiest. Also, to make the evaluations fair, only the free versions of each software program were evaluated.

The first tool evaluated was Ultiboard from National Instruments [1]. The software used was a free download of the student version. Ultiboard can be downloaded from http://www.ni.com/multisim/try/. This version was the first choice, because the educational version was already being used at Purdue University and was already a relatively familiar program for the authors. Ultiboard is paired with a schematic editor called Multisim, which is capable of simulating circuits and generating both numeric and graphical data outputs [2]. There are even versions of Multisim and Ultiboard that connect to Mouser Electronics to determine cost and availability of components used, and can assist in ordering everything needed for a completed PCB. More information about this version can be found on the Electropages.com website. These extra features supported by Multisim and Ultiboard make the software package seem more appealing than others that only produce schematics and PCBs.

The second tool evaluated was PCB Artist from Advanced Circuits [3]. It is free to use for the general public and offers the capability to order completed PCBs straight from within the project window. Their website offers helpful links to information such as general lookup tables and tutorials at http://www.4pcb.com/free-pcb-layout-software/. PCB Artist is a program widely used by both hobbyists and small businesses. PCB Artist was chosen because it offers many of the same features as other paid tools, without limiting the use of the software [4].

The third tool chosen for the evaluation was Eagle from Cadsoft USA [5]. A free Light Edition is offered to the general public for trial use. Customer reviews, such as the one found on Provideyourown.com's article, show that there have been a few complaints [6]. The authors of this current study found that the software lacks a user-friendly interface; that the free version of the software limits PCB size to very small dimensions, which limits what can be built; and that most of the tools required to design the circuit and lay out the PCB are hard to use and require a lengthy process of steps in order to build the same things, compared to other layout software. Eagle was chosen due to its use in industry, despite online reviews criticizing the software as difficult to use. Several other tools, such as PCB Web, FreePCB, and KiCAD, were investigated but not chosen for thorough evaluations [7-9]. Most of them support many of the same features as the ones chosen for evaluation. Table 1 lists the features for all of the tools mentioned.

PCB Evaluation: Ultiboard

National Instrument's student version of Ultiboard, in conjunction with Multisim, were used for the first evaluation. Both are very powerful programs when used separately; and, when combined, become even more useful for designing, building, testing, and laying out circuits. The package offers the capability of using one software package to complete the job from start to finish. With the use of Multisim's extensive simulation capabilities, building a protoboard circuit to test before PCB layout is an optional step, depending on the requirements of the circuit being created.

Table 1. Feature Comparison of PCB Layout Tools

PCB Tool	Ulti-board	PCB Artist	Eagle	PCB Web	Free PCB	KiCAD
Vendor	National Instruments	Advanced Circuits	Cadsoft USA	PCB Web	Free PCB	EDA Software Suite
System Requirements	Win	Win	Win, Linux, MAC	Win	[redacted]	Win, Linux,MAC
Download Web Site	ni.com	4pcb.com	cadsoftusa.com	pcbweb.com	freepcb.com	kicad-pcb.org
Gerber Files	Yes	Free after order	Yes	[redacted]	Yes	Yes
Ftprt Wizard	Yes	Yes	Yes	[redacted]	Yes	Yes
Rule Checking	Yes	Yes	Yes	[redacted]	Yes	Yes
Part Library	Yes	Yes	Yes	[redacted]	Yes	Yes
Cu Layers	2-64	6	2 max (free)	[redacted]	1-16	32
Board Size	2m x 2m	18” x 58”	100 mm x 80 mm	[redacted]	60” x 60”	[redacted]
English/Metric Units	Yes	Yes	Yes	[redacted]	Yes	Yes

For this evaluation, a circuit was provided that takes a logic input and turns on transistors to drive solenoids that actuate parts on a humanoid robot. Figure 1 shows the first step of the process—to construct the schematic in Multisim. Once complete, it can be edited and simulated to ensure that everything is working properly. The circuit design steps in Multisim have been omitted here, since this portion is not being evaluated. Connections and components can be added, altered, or deleted at any time. Organization of component location and wire connections of the circuit in Multisim is not crucial for the layout of the PCB in Ultiboard. One aspect of the circuit design process that is crucial is making sure each component label matches what is expected. For example, if a specific resistor should be labeled R1 or R2, this is the time to make sure that the labels match the corresponding components. Once transferred into Ultiboard, these labels will stay with the corresponding components so that they can be printed into the silkscreen of the board to identify component location for soldering after the board is printed. If a location is improperly labeled, this could result in components being soldered into the wrong places. The wire connections in Multisim are just connections, not layout information.

Once the circuit is correct in Multisim, it can be transferred into Ultiboard to begin the process of PCB layout. Figure 2 shows this to be one of the simplest processes within the software package, only requiring a few clicks of the mouse.

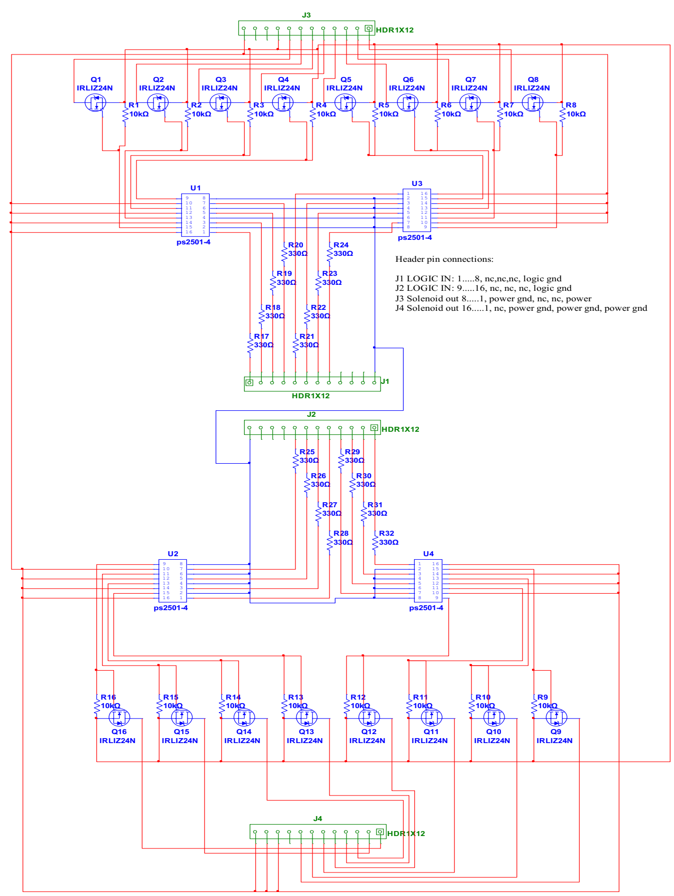

Figure 1. Multisim Schematic

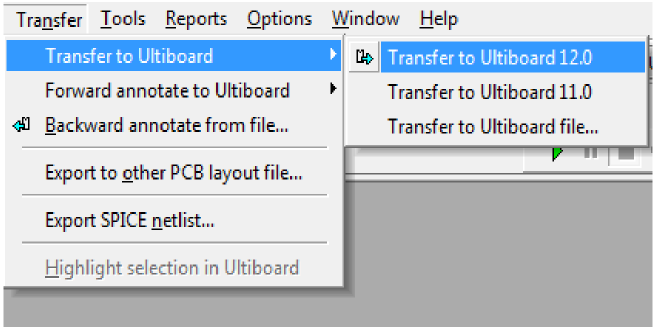

Figure 2. Transferring the Multisim Circuit to Ultiboard

Once the circuit is successfully transferred into Ultiboard, PCB layout can begin. Figure 3 shows that, when Ultiboard first imports the desired circuit, all of the components are placed in order at the top of the screen.

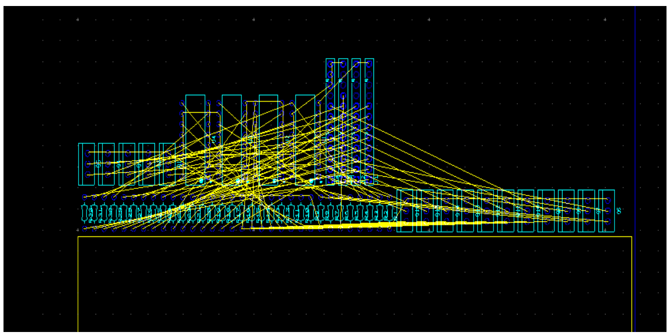

Figure 3. Multisim Circuit Imported into Ultiboard

Notice that all of the intricate routing of the connections made previously in Multisim are no longer present. Ultiboard only knows what components/pins are tied together. The yellow web of lines among the components depicts the connections previously made in Multisim. These virtual connections are called nets, and will need to be rerouted and transformed into copper traces, once the parts have been placed appropriately on the board. With so many components jumbled together at the top of the screen, one option to speed up the process of getting them onto the board would be to use the Autoplace parts function located on the top toolbar. Figure 4 shows that by clicking this button, Ultiboard takes the parts on the screen and places them within the confines of the specified PCB, which is the large yellow rectangle on the screen. Using this option has the potential of being both helpful and harmful. If a simple circuit is being built with minimal components, then using the Autoplace parts button is probably a fairly safe option. However, when building larger circuits that contain many components or require a large number of connections, such as this one, having the software randomly placing components onto the board could make it very difficult to locate specific components.

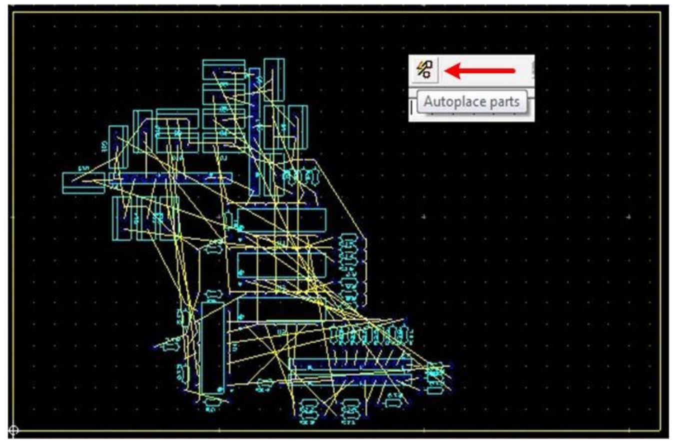

Figure 4. Autoplace Parts

Individual components can still be selected and moved anywhere across the screen both before and after using the Autoplace parts feature. From this point forward, the final board layout will be reliant on several factors: board size, number of copper layers, and user patience. Before laying out any board traces, it is usually best to arrange each component on the board in order to minimize the number of yellow connection lines crossing each other. If the circuit is very complex, making the board size larger or increasing the number of copper layers will be crucial in simplifying this step. For this circuit, the default board size was used, as well as the minimum 2-copper-layer board for thru-hole components. Arranging components with a minimum number of crossing connections can take anywhere from minutes to hours to days, depending on the complexity of the circuit and the patience of the user. Two crossing traces are generally accommodated with a via, which is an electrical connection extending vertically between two (or more) copper layers. A pair of vias can be used to transfer a trace to a different layer, allowing it to pass under the other trace, then return to the original layer without making electrical contact. Circuit layouts with a large number of crossing connections require more vias.

Figure 5 shows the beginning of this layout process. Notice the header pins and resistors in the lower right portion of the PCB. These components are tied together uniformly and have been arranged without crossing connections. A layout like this will result in very simple traces that do not interfere with other connections. Some parts may need to be moved or rearranged multiple times in order to ensure the cleanliness of traces throughout the board. Component placement is entirely at the user's discretion. One thing that Ultiboard will not do is tell the user if components or connections that are close together will create noise that could result in a malfunctioning circuit. The user must plan for RFI and crosstalk prior to the final design.

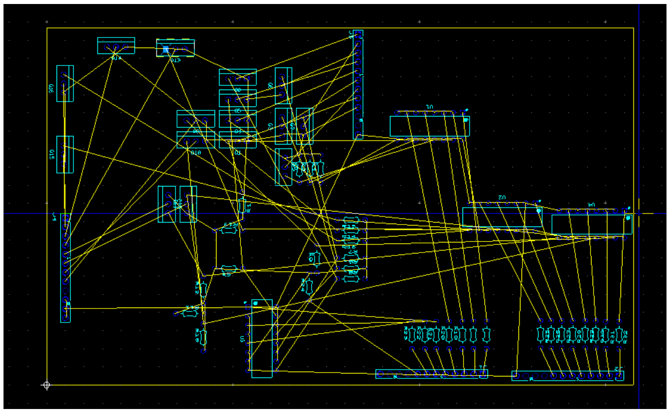

Figure 5. Start of Arranging Components in Ultiboard

Once the components are arranged, the form of the circuit begins to take shape. Figure 6 shows the final layout of components for this board. Notice there are still crossing connection lines, but most of these connections are still going in the same direction. This is also going to be a two-layer board, so if two traces intersect, part of one can be transferred to the other layer to avoid contact.

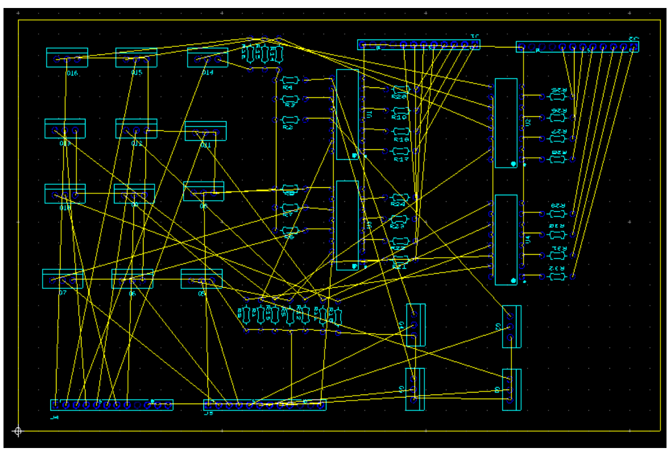

Figure 6. Final Component Layout

Traces in Ultiboard can be made several different ways. One way is by drawing them individually. This can be a time-consuming process, but is often the best choice for producing a very clean circuit. This is the only way to lay out traces, while making sure that every connection made goes exactly where desired. To make a trace, click on the Follow-me button, as seen in Figure 7. Then click on a pin of any component where a connection is to be made and it will snap to the previous yellow lines. A trace can be made anywhere on the board. If the trace stops and the full connection has not been made, then the yellow connection line will continue from where the trace leaves off and proceed to where the desired connection needs to be made. If there is another trace in the way, click on the via button (see Figure 8). This button will make a small plated hole carrying your connection through the board to the bottom. Figure 9 shows that once a via has been made, the user can navigate to the Layer drop-down tab and choose, for example, to go from drawing on the top layer of the board to the bottom layer of the board. Once the bottom of the board has been chosen, the user can continue from the via across the bottom of the board until a connection has been made or until there is a need to move the trace to another layer by adding another via. Figure 10 shows an example of traces going from top layer to bottom and back. Green lines are the top layer traces, red lines are the bottom layer traces, and the blue circles are the plated vias that go all the way through the board.

Figure 7. Follow-me (button)

Figure 8. Via (button)

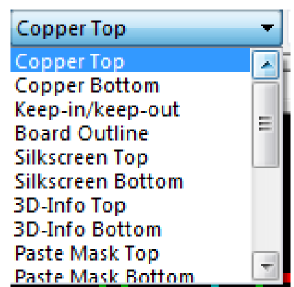

Figure 9. Layers (drop-down selection)

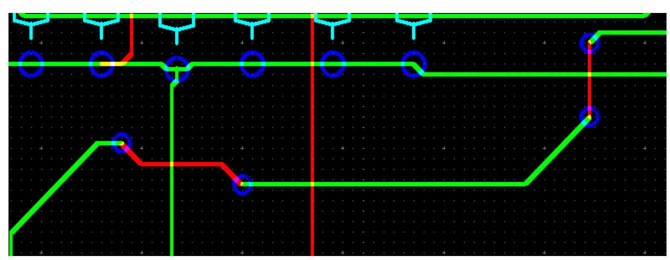

Figure 10. Top and Bottom Traces

The user can also use the auto trace feature. This will give the software full control of your circuit to draw all of the traces wherever it chooses. Figure 11 shows the results of the auto trace feature on this circuit. This process is much quicker than drawing them manually. Although this process not bad, it should not be trusted completely. All of the required connections get placed on the board in traces, but some may be too close to one another or have otherwise been placed poorly. Luckily, traces can still be moved or deleted altogether and redrawn.

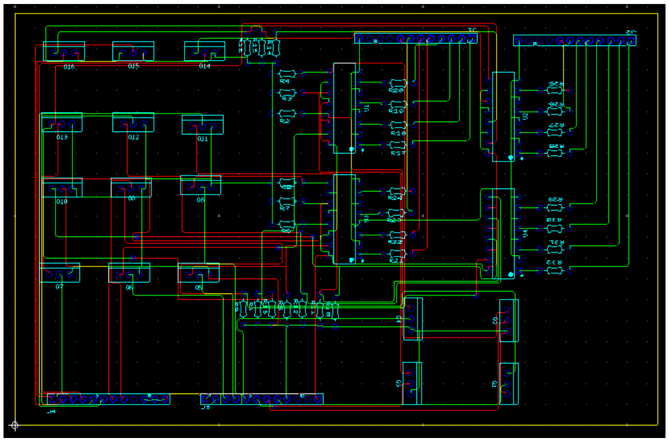

Figure 11. Auto Trace

Once the traces on the board are placed, it might be desired to add further text to the silkscreen on the board to display additional information about the circuit. Figure 12 shows how text can be inserted by clicking the **Text** button from the toolbar. This allows the user to drag a box onto the screen and type the desired text. Once this is done, the textbox can be moved anywhere on the circuit board.

Figure 12. Insert Text (button)

Figure 13 illustrates what text on the board looks like. This text will be nonconductive printing on the silkscreen, which will display information to the user as an indication of what connection is being made for each one of the header pins. This is important information, since wiring harnesses will be plugged into these headers and it is very important that they get plugged into the correct header pins and also in the correct direction.

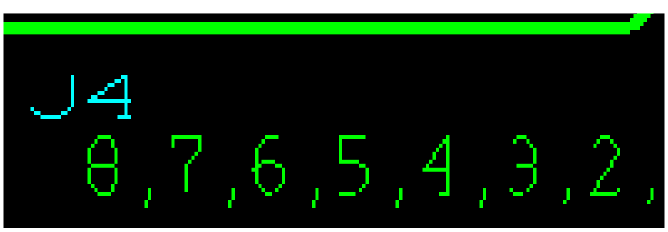

Figure 13. Example of Text on Board

Figure 14 shows the entire board with all of the trace connections, as well as the silkscreen text indicating each header pin.

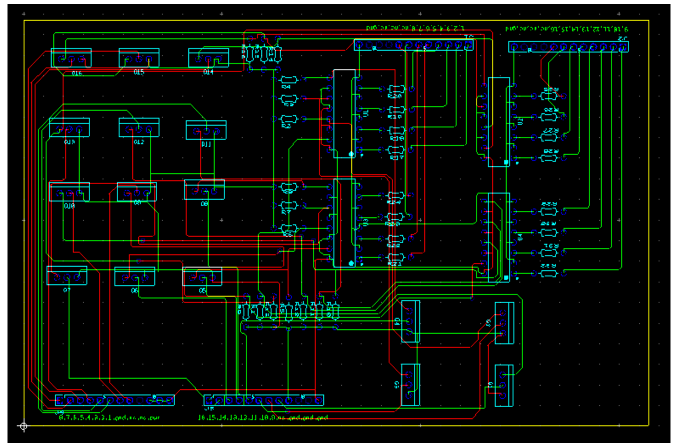

Figure 14. Circuit with Silkscreen Text

At this point in the PCB layout process, the circuit could be considered complete, or the user could continue refining the layout. Figure 15 shows the completed layout of the circuit for this evaluation, as well as the Ultiboard-generated 3D model of what the circuit will look like after the board has been printed and all components have been soldered into the correct places.

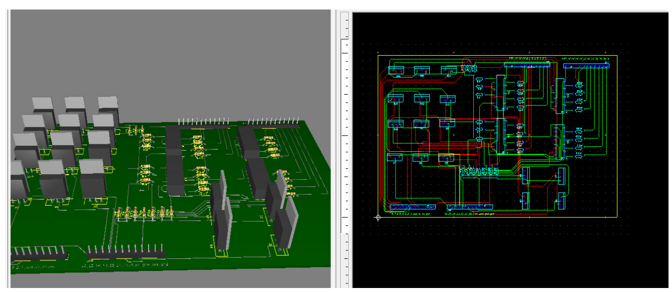

Figure 15. Ultiboard Completed Layout with 3D Model

Overall, Ultiboard and Multisim form a very user-friendly and easy-to-use software package. All of the important features, such as via, text, trace, and board options, are easy to access, with most of them being located in the top toolbar section.

PCB Evaluation: PCB Artist

For this evaluation, PCB Artist from Advanced Circuits was used. This is a free software package that goes beyond schematic design and PCB layout. With this software, the files can be sent directly to Advanced Circuits to have a board printed and delivered. Price scales are included to display how much the project is going to cost per board at each step. Upon first impression, this software program operates similarly to other CAD (computer aided design) software packages. Even when scrolling and navigating around the screen to see different parts of the project being created, the controls operate very similarly to what would be expected in an expensive CAD software package. If the user has experience using CAD programs, learning how to use PCB Artist will likely be quite simple.

This evaluation was done using the same circuit as the Multisim evaluation. The first step of the PCB design process was to build the schematic. Choosing a component to use can be somewhat difficult at times. All components are sorted by manufacturer, and then by part number in alphabetical order. While PCB Artist does offer a wide selection of parts, some of the specific parts for the circuit in this evaluation were unavailable within its part library. This evaluation used components with common footprints. After some research, substitute components were chosen that share the same footprint. Although this was a relatively simple fix, it was a very frustrating roadblock early on in the design process.

The wire connections from the schematic tell the software which nets to make when the PCB is constructed. Nets are virtual connections that exist among pins of the parts that are to be connected together with a wire or board trace. These nets tell the user where connections need to be made once the schematic is completed and the layout of the PCB begins. Figure 16 shows a completed schematic for this evaluation.

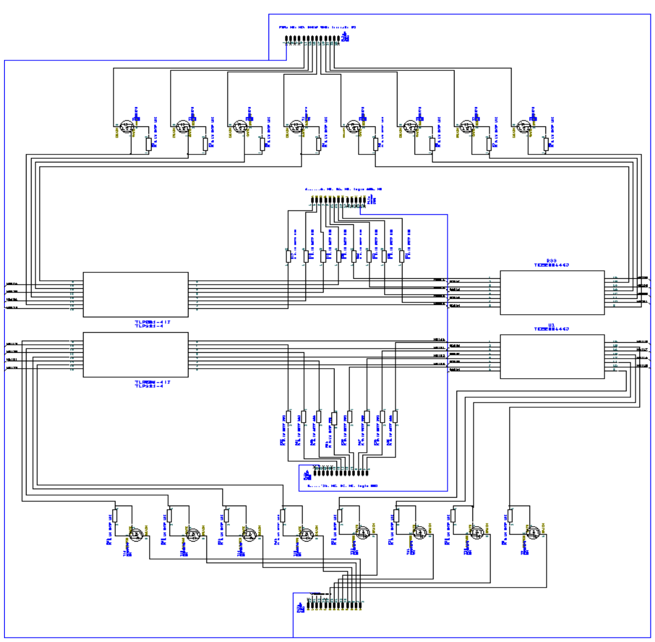

Figure 16. PCB Artist Schematic

Once the schematic is finished, the circuit needs to be forward annotated to the PCB layout side of the software program. This can be done from the Tools dropdown menu located in the upper toolbar. Figure 17 shows the dropdown menu with “Translate To PCB...” highlighted. Clicking this will begin the setup for the PCB layout portion of the design.

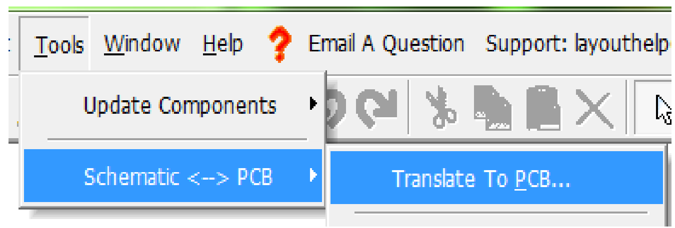

Figure 17. Translate to PCB Menu

While translating the circuit to begin drawing the PCB, the user will be prompted to make choices on its specifications. During configuration of the board, all associated prices are displayed for a total cost to build the board when ordered. Figure 18 shows the bottom left corner of the board specification screen that displays the Unit Price as well as the subtotal, as selections are made.

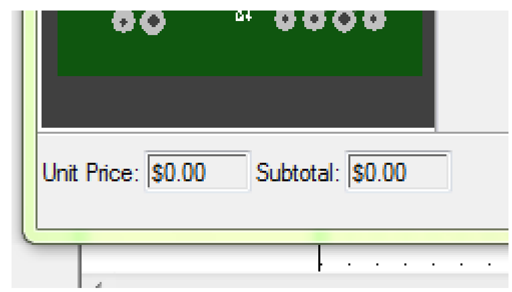

Figure 18. Price of PCB

From within this window, numerous specifications to determine the outcome of the finished board can be changed, such as board size, number of layers, and trace requirements for each layer. Be careful not to get carried away with the settings. Basic settings were chosen for this evaluation and a unit price of $326.50 was calculated, if the board was to be ordered through their vendor. Once all of the necessary board specifications have been met, the PCB layout portion of the software will open and the components from the schematic can be placed onto the screen. Figure 19 shows the components laid out in the workspace, in order, with all of the yellow net lines stretched among them.

PCB Artist does have the capability to automatically place parts within the board space, as well as automatically place the connection traces where needed. For this evaluation, all of the component and trace placements were executed manually to ensure a clean layout. Figure 20 shows the rough beginning of a board layout with some of the trace connections already made. Notice that both the solder pads and completed traces are red in color. Red is the color for anything copper on the top board layer. The yellow lines between components are the net connections that still need to be placed onto the board.

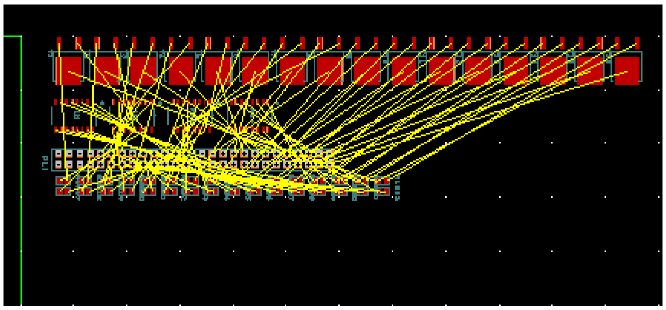

Figure 19. PCB Artist Parts Placed

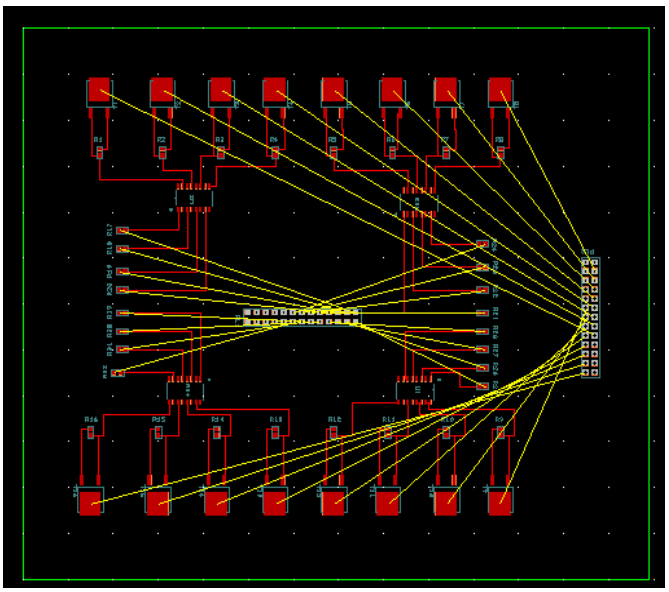

Figure 20. Components Placed on Board for Organization with Some Traces Made

If it is required to transfer from using the top layer of the board to the bottom layer, all the user needs to do is press the letter “L” on the keyboard while the trace tool is selected and a menu screen will open asking to specify the layer. If the choice was made to switch layers before a trace has been completed, then a via will automatically be placed at the point where the layer transfer happens and the user can continue drawing from this location on another layer. This is a nice way to switch back and forth between layers with a simple hotkey. On the display, copper traces on the bottom layer of the board are highlighted in light blue. The vias created when this layer transfer happens are highlighted in yellow. Figure 21 illustrates several layer transfers.

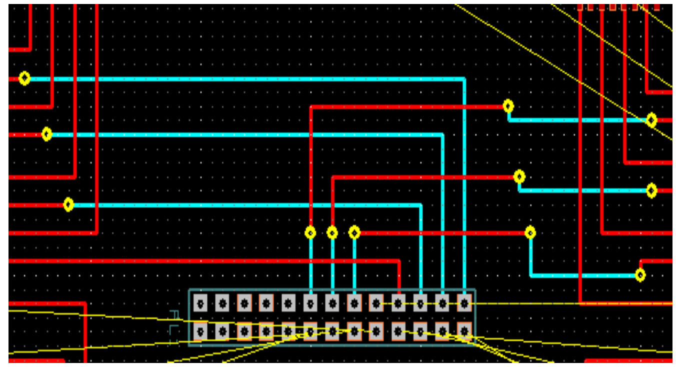

Figure 21. PCB Layout Vias and Layer Transfers

A good practice in PCB layout, especially for RF signal traces, is to use 45° chamfered corners when possible instead of hard 90° corners. When traces are drawn, PCB Artist assumes that corners will be set at 90°. In order to change the corners of a trace, double-click on the corner to be chamfered, then drag the corner in toward the center of the turn. The corner can then be moved with the chamfer in place to wherever desired. Figure 22 shows traces that are both chamfered and not chamfered. Chamfered corners also often allow for tighter turns and closer component placement. Figure 22 also shows, in this case, how traces without the chamfers stick out much further than needed.

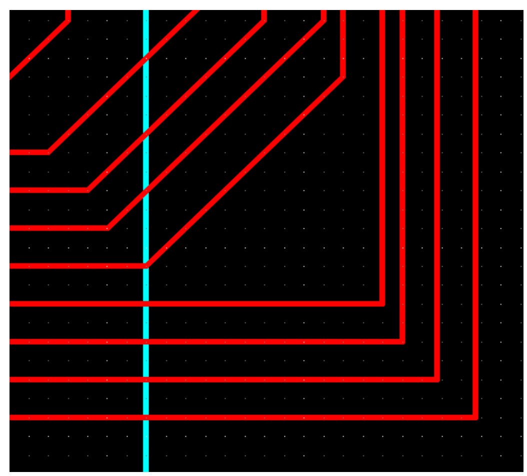

Figure 22. Chamfered Corners

Within PCB Artist, the user can also print copper shapes. For this evaluation circuit, the chips being used required separate grounds isolating the two sides of the photocouplers. These grounds come in from the header pin connections located elsewhere on the board. Instead of routing each ground connection separately, the copper shape tool can be used to create a ground plane on the bottom layer, as shown in turquoise in Figure 23. This approach minimized interference with other copper trace connections, while allowing ground connections with simple vias.

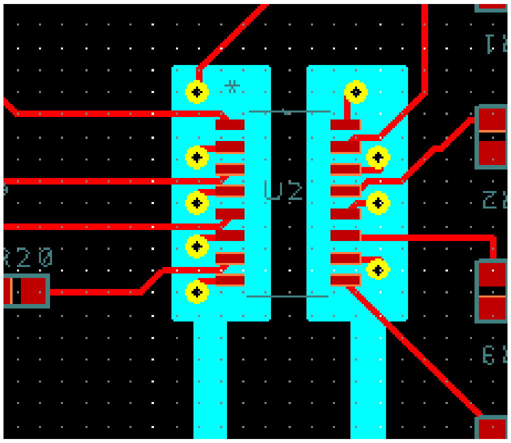

Figure 23. Bottom Copper Layer Ground Plane

Figure 24 shows the final form of the circuit for this evaluation. The PCB Artist software program from Advanced Circuits got steadily easier to use, as the author continued the evaluation. The most difficult thing to do within the software was to locate parts that could be used in the circuit. This evaluation modified the original design to use SMT components instead of thru-hole components. Instead of being able to look up the components by type then availability within the program, it was by manufacturer then alphabetically. This seemed to be a messy way of listing the parts, since like components were not necessarily together with one another. This made things difficult because, when needed, specific components were not available within the libraries of the software. This resulted in wasted time and frustration in order to proceed with the design. Despite this minor upset obtained from using PCB Artist, the rest of the software was extraordinarily easy to navigate. The arrangement of each menu screen and toolbar was simple and functions were easy to find. It would not take long for a person with PCB layout knowledge to learn how to produce a quality board with this software.

PCB Evaluation: Eagle

For this evaluation, the free Light Edition of CadSoft's Eagle was used. This version does not contain all of the capabilities of the paid version. Upon first impression, Eagle appeared very different from the other layout tools. While most of the tools used in Eagle are the same as those in other programs, they behave somewhat differently. The authors' impression is that Eagle was targeted for experienced users. Unlike some of the other PCB programs on the market, Eagle bases all design elements from the original schematic. If anything needs to be changed along the way, such as a net change, the user needs to go to the original schematic and forward annotate the changes from there. This process may seem tedious jumping from screen to screen, but for documentation purposes it makes sense to have everything matching. Once the project is complete, all of the corresponding files will then mirror each other. Eagle prompts the user with an error message when an action being performed in the board space needs to be altered in the schematic. This way the user knows when to jump between screens. The Eagle components library also seems to be more extensive than others on the market, with an adequate mix of SMD (surface-mount device) and thru-hole components. A limitation of the free Light Edition is that PCB board space is limited to a size of 100 x 80 mm (3.94 x 3.15 inches). If a circuit with a large number of components is being constructed, SMD components should be used as much as possible.

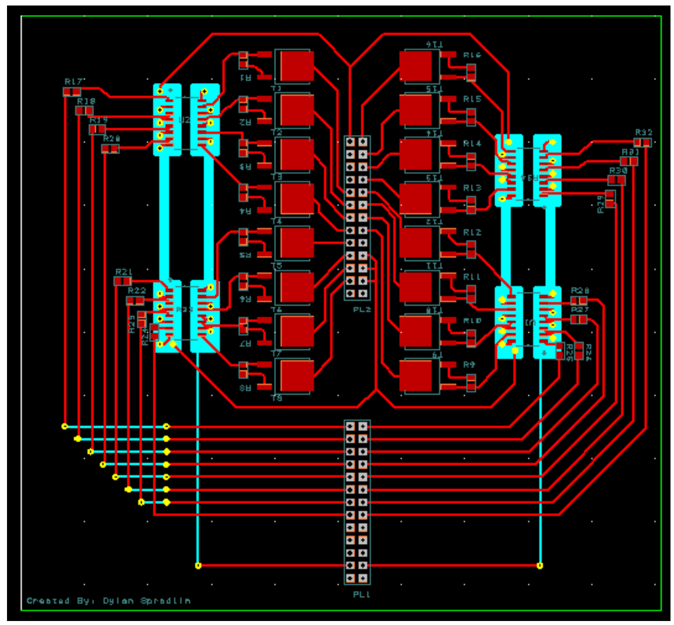

Figure 24. PCB Artist Completed Evaluation Circuit

One thing to also note, during the schematic phase of the design, is to make sure that wire connections are actually connected to the components. In several instances of this evaluation, connections appeared to be attached; but, when transferred to the PCB, they in fact were not. The fix is simple: Go back into the schematic and adjust the connection, which automatically gets forward annotated to the PCB. This can, however, become tedious and frustrating, if too many connections need to be fixed. Figure 25 displays the completed schematic using Eagle.

Once the schematic is finished, transferring to the PCB is very similar to the other programs. Simply go to the File menu and choose "Switch to Board," as shown in Figure 26. The program will prompt that the **.brd** file has not been created and ask for one to be created.

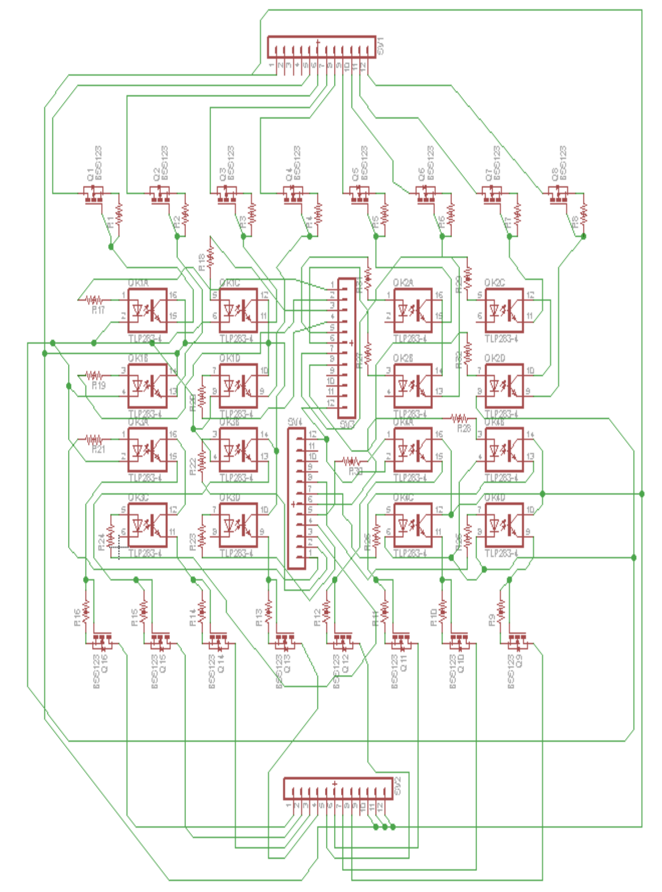

Figure 25. Eagle Schematic

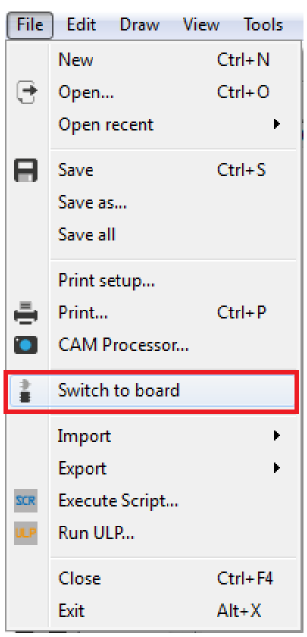

Figure 26. Switch to Board

Like other PCB layout programs, when the board editor is first opened, all of the components used and their net connections are displayed on the screen in order by component type, as shown in Figure 27. The box seen next to the components is the usable board space for the PCB, which is fixed in the free Light Edition. Another limitation of the free version is that only top and bottom layers of copper can be used to make a board. There are other free software programs available, such as PCB Artist, which will allow for six layers to be used.

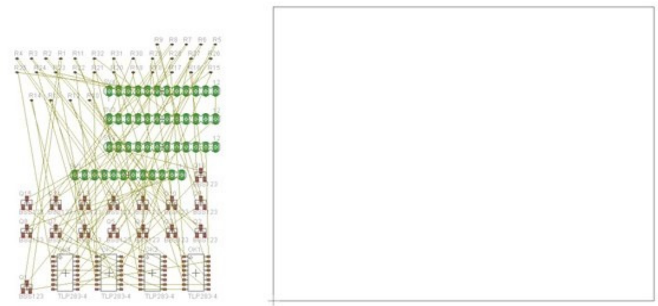

Figure 27. Initial Component Layout (left) and Blank PCB

One drawback of Eagle is that it does not allow temporary placement of components outside of the board space. Sometimes it is helpful to move components around the workspace to organize them before placing them on the board, but Eagle will not allow this. If a component is moved from the original start location to any spot other than inside the board, a message will prompt the user that this move is invalid. Although not detrimental to the design process, it does make beginning the layout slightly more difficult. Moving multiple components at once is also not very intuitive. In other programs you can simply select all of the components to be moved, click on one of them, and drag them all across the screen. The process in Eagle is similar, but once the components are selected, and before dragging them, the user must first right click on the selected group of components and select "Move: Group" (see Figure 28). If this step is not done, regardless if there is one or multiple components selected, then only the single component that is clicked on and dragged will move.

Another feature of Eagle that can be confusing is that there are two tools that can be used to draw copper traces on the board space. Figure 29 shows these two tools outlined in a red box. The tool on the top is the route tool. This one is for connecting nets together and will actually lock on to solder pads automatically when a trace is beginning or ending near one. The tool underneath is the wire tool. This will allow the user to free-draw copper traces on the board, but will not lock on to the solder pads. Both can accomplish the same end result, but the route tool is a more reliable approach for making contact with a solder pad.

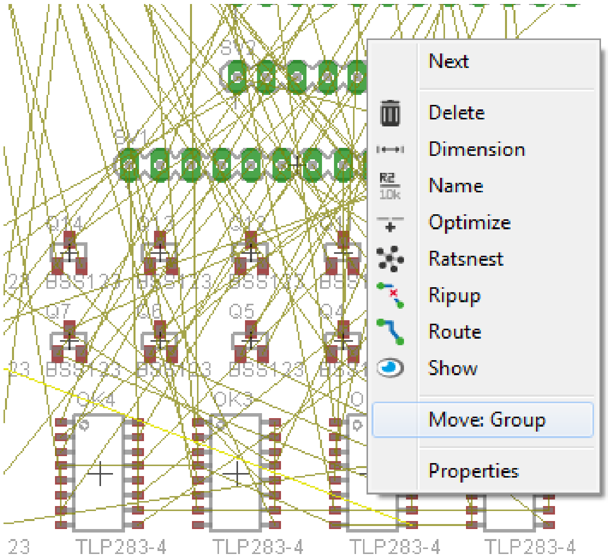

Figure 28. Move: Group

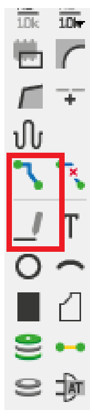

Figure 29. Copper Trace Tools

The top copper layer is displayed on the board in a maroon color. When it is time to transfer the trace to the bottom layer, end the current trace by either clicking again on its end point or by pressing the **Esc** key on the keyboard. Then, from the left-side tool bar, select the via tool, as shown in Figure 30. Figure 31 shows how to use the via hole to place a via at the end point of a trace that was previously placed on the board. Once the via is in place, re-select the route tool from the tool bar and use the dropdown menu seen in Figure 32 to switch to the bottom layer of the board. Blue traces on the board editor represent traces that are drawn on the bottom layer. One nice feature is a chime that sounds when a trace is completed for a given net.

Eagle is a very powerful program when full customization is desired. Other customizable features of Eagle not covered in this evaluation include adjusting trace widths, hole sizes for drilling, and size tolerances. With these adjustments in place, a user will be able to produce a fairly high-quality board without paying for the software, though it is difficult to pick up and use for a first-time user. One big frustration in using it for the first time was not knowing how to move multiple components at once until the **Move: Group** operation was discovered. One might expect such simple operations to be more intuitive. Eagle offers more options for customization and seems to be far more advanced than other free programs on the market.

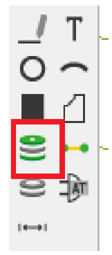

Figure 30. Eagle Via Tool

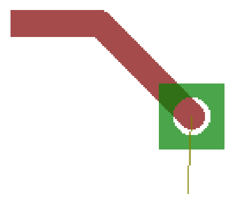

Figure 31. Eagle Via on Board

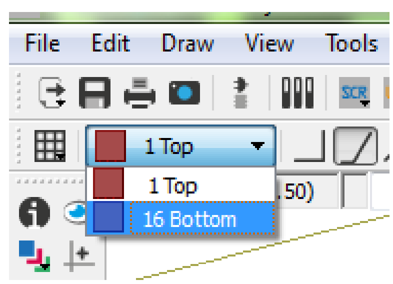

Figure 32. Layer Selection Menu

On the other hand, there are several limitations of the free Light Edition. Board space is limited, which forces the user to make multiple smaller boards to complete larger circuits; layer usage is limited; and the schematic editor is limited to only being able to create one sheet per save file. Moreover, customer support for the Eagle Light Edition is limited to email only, while paid versions also offer fax and phone support. Finally, use of the free version is limited to non-profit applications or for evaluation purposes only, per their user license agreement. It appears that the free version is intended primarily as a demo before purchasing the full version. Figure 33 shows a completed PCB layout for this evaluation.

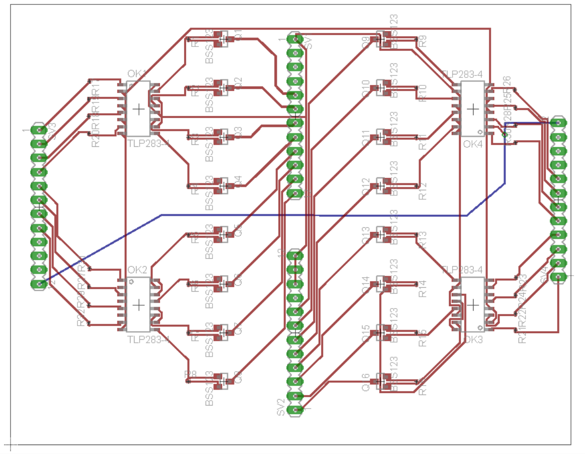

Figure 33. Evaluation Circuit Completed in Eagle

The limitations listed here mean that the free version of Eagle may not be adequate for many situations. Alternatives include using another free package, or paying Cadsoft for one or more important features of the paid version. Depending on the features being unlocked and the number of users per license, this could cost anywhere from $69 up to several thousand dollars.

Conclusions

This evaluation was restricted to the free versions of Ultiboard, PCB Artist, and Eagle. Although all three are good programs and well capable of producing a high-quality PCB, the authors found that Ultiboard appeared to be the best for an educational environment, and PCB Artist may be the best for an industrial setting. Of the tools reviewed, National Instruments' Ultiboard is versatile, when considered in conjunction with the companion circuit simulation package, Multisim. Neither PCB Artist nor Eagle support circuit simulation. Ultiboard allows up to 64 copper layers, whereas Eagle only permits two, and PCB Artist allows six. Moreover, Ultiboard allows a board size of up to 2m x 2m, compared to 100 mm x 80 mm in Eagle, and 18" x 58" in PCB Artist. Ultiboard also allows users to make custom footprints for parts not included within the library. Finally, Ultiboard offers a 3D visual rendering of what the final PCB will look like after the components are installed. This feature is not found in PCB Artist or Eagle.

But one should also consider that PCB Artist behaves similarly to CAD programs in the way that the user navigates around the screen and uses the tools available for constructing a PCB. Moreover, PCB Artist makes ordering very simple by giving users the capability of ordering the PCB from within the program. This makes the process of physically obtaining the board easier. This helpful feature eliminates the need for locating a company to produce the PCB and sending in all of the design files manually. Unfortunately, the output is a proprietary format intended for ordering from Advanced Circuits, not the standard Gerber file format. All three of the layout tools work well. The ultimate choice will depend on user preference, whether circuit simulation is needed, and the company/academic environment.

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SMART-GRID EMULATOR WITH A HARDWARE IN-LOOP SMART-METER INFRASTRUCTURE

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Abstract

A smart grid is a combination of an electrical network and a data communications network. Smart-grid simulation requires the simulation of the electrical power flow and the data flow. There are a number of tools available for doing these two tasks independently but only a handful of tools available for the combined simulations. In fact, simulating wireless networks used in advanced metering infrastructure (AMI) and other smart-grid applications is not easy and requires attention to detail. A smart-grid emulator focuses on the electrical distribution system and the overlaid AMI network, while using software tools to model and simulate the power system before integrating it with the real-world smart-metering network. This eliminates explicit modeling of the communication network in software and helps capture the true characteristics of the communication network. In this paper, the authors discuss a hardware in-loop test bead for emulating the planned smart grid with AMI.

Introduction

Distributed energy resources (DER) play an important and a major role in modern smart-grid and micro-grid systems [1]. DERs, mostly renewable energy-based DERs, are receiving more attention from the power industry, due to recent advancements of technology and consumer demand for clean energy and energy independence [1, 2]. DERs have not only become a way to provide clean energy, but also a way to reach the loads that cannot easily be reached by traditional transmission networks. They also provide a way to stabilize the grid [3]. DERs should be planned and placed in an optimal manner to get maximum usage. Allocation of DERs in a distribution network needs to be done in a systematic way to avoid system instability [4-9].

In this paper, the authors also discuss a hardware in-loop emulator for emulating the behavior of smart grid or micro-grid systems with DERs and time-varying loads. This system incorporates an advanced metering infrastructure (AMI) in the distribution network with hardware-controlled loads. The hardware in-loop emulator is a subsystem of a tool that use multi-agent systems (MAS) for DER allocation planning. MAS has been used in many applications over the past decade [10]. More research has been conducted on usage of MAS in power system control than in power system planning [11-17]. Research done in power system planning using MAS is more focused on market-oriented planning [18, 19]. The proposed MAS-based planning tool emphasizes engineering and technical aspects as well as looks at how to find the best location, capacity, and type of DER to suit a given power distribution network. Figure 1 shows a functional diagram of the MAS-based DER planning tool. The marked area shows the functionality of the hardware in-loop emulator and the place that it fits in the DER planning tool.

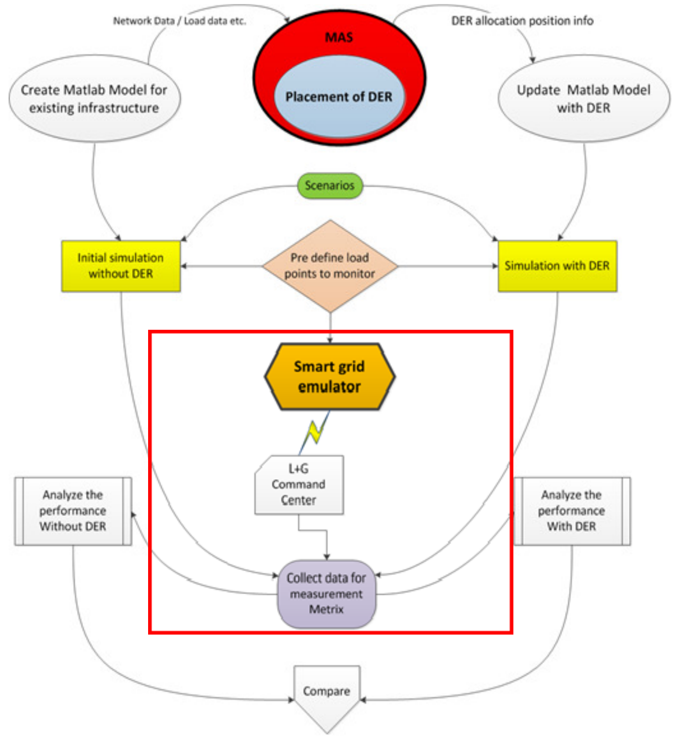


Figure 1. MAS-Based Distributed Energy Resource Planning Tool

Emulators can also be used as a training tool. Students can use the emulator to experiment with the AMI network and its interaction with the power distribution system. Building a power distribution system in a laboratory environment with distributed generation and modern smart-grid technology is costly. The proposed emulator offers a cost-effective system to study the use of the AMI and its interaction with power distribution systems. Smart meters in the emulator can be assigned to selected loads in the simulated distribution system. The simulation can be done for different scenarios and interval data can be collected from the AMI. These data can be used to study the applications for the AMI. For an example, how fast should the data be collected in order to correctly predict possible outages, or how accurately the collective set of smart-meter data can represent the status of the grid.

Simulation tools, such as MATLAB, PowerFactory, and OpenDSS, are available for power system simulation. Network simulators such as NS2, OPNET, and OMNET++ can be used to simulate the behavior of the AMI. A gap exists in simulating the collective behavior of the power system and the AMI. How the AMI will help to collect data to analyze the status of the grid and how constraints such as available bandwidth and hardware limitations in the AMI will affect the application. These are hard to analyze using two separate simulators. The integrated simulator can be built in software, but an actual hardware AMI will provide the true behavior of the system.

Literature Review

Many commercial and open source power system simulators are available to simulate smart grids. Most of these simulators were originally focused on traditional power system simulation and later improved to incorporate smart-grid technologies such as renewable energy, storage units etc. Matlab provides a set of tools for power system simulation. MATPOWER provides a script-based simulation tool for power flow analysis [20]. SimPowerSystem toolbox in Matlab Simulink provides graphical modeling of power systems. SimPowerSystem toolbox supports modern smart-grid technologies including renewable energy generation, storage technology and inverter-converter technology [21]. SimPowerSystem toolbox itself does not provide any SCADA or AMI components that can be incorporated into the power system simulation. However, Matlab has many other toolboxes, such as communication toolbox, that can be incorporated with the SimPowerSystem toolbox to simulate the SCADA and other wireless monitoring and control networks associated with the smart grid.

PowerFactorTM [22] provides a wide variety of tool for modeling and analyzing the power systems. PowerFactory provides renewable energy, storage technology, inverter and converter technologies to facilitate the smart-grid simulation. A wide range of functions is supported, including power-flow analysis, short-circuit analysis, reliability analysis, and quasi-dynamic simulation. PowerFactory does not provide direct support for SCADA and communication system incorporation. However, its ability to control the power system components using the DigSILENT programming language (DPL) could be used to model the communications layer.

OpenDSS is an open source software specifically designed for distribution analyses such as distribution generation analysis [23]. OpenDSS does not support time-domain analyses. OpenDSS does not provide a platform to incorporate SCADA, AMI, or any other communication structures associated with the smart grid. Network simulators are available to simulate the wired and wireless network infrastructure. These simulators can be used to study the behavior of SCADA and AMI networks associated with the smart grid. Network simulators such as NS2, OPNET, OMNET++ can be used to study the bandwidth limitations, interference, and other network properties associated with AMI and SCADA. Nevertheless, their inability to easily combine these simulators with power system simulation tools degrades the essence of such simulations. Actual AMI or SCADA systems have limitations in network parameters as well as associated hardware, such as processing power, storage capacity, etc. Only a real system can be used to truly study the effects due to such limitations.

The emulator in this study used an actual hardware AMI, which reflected the actual behavior of the AMI. The emulator also provided a software simulator for modeling and simulating the power grid and facilitated the interconnection between the hardware AMI and the software-based power system simulator. This provided a unique ability to model the entire power system with the associated communication infrastructure. The real AMI network helped to investigate the true behavior of the communication network, including bandwidth limitations, limitations in processing power, and limitations in storage with the associated delays.

Functional Overview of the Emulator

The smart-grid emulator consists of a power system simulator and a set of controllable hardware loads attached to smart meters. Hardware and software parts of the emulator are integrated via USB to an I^2C converter with the support of an input-output (IO) expander. The grid can be modeled using either Matlab PowerFactory [22]. This section describes the modeling of the grid using Matlab and how the grid is integrated with the hardware components of the emulator.

Modeling the Grid Using Matlab

Matlab Simulink and SimPowerSystems toolbox were used to model the grid. In order to model the grid with time-varying loads and hardware in-loop components, user-defined modules had to be created. These modules consisted of time-varying single-phase loads, time-varying three-phase loads, and components that support signal flow from simulator to external hardware controllers.

Figure 2 shows how load data are read by the single-phase and three-phase time-varying loads. Figure 3 shows the Matlab Simulink model developed to select active (P) and reactive (Q) power from a spreadsheet file with load data. The selected P and Q values simulated the time-varying power demand of the load and were inserted into single-phase or three-phase dynamic load models as an input. Each of these software load models was associated with a smart meter and controllable loads in the hardware emulator. Voltage and current data for each load were written to Matlab during the simulation and then used to control the hardware loads. Figure 4 shows the message and signal flow in the hardware in-loop emulator.

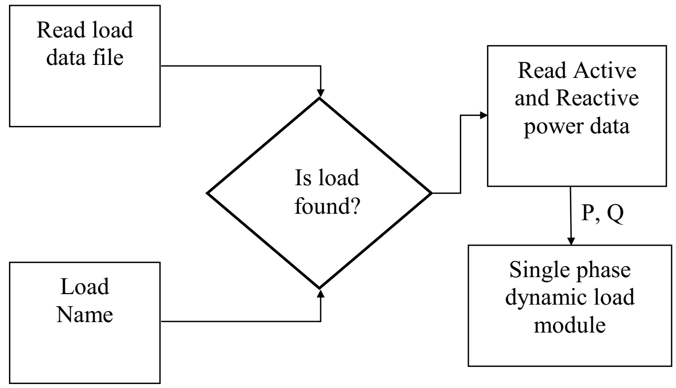


Figure 2. Single-Phase Time-Varying Load Model in Matlab Simulink

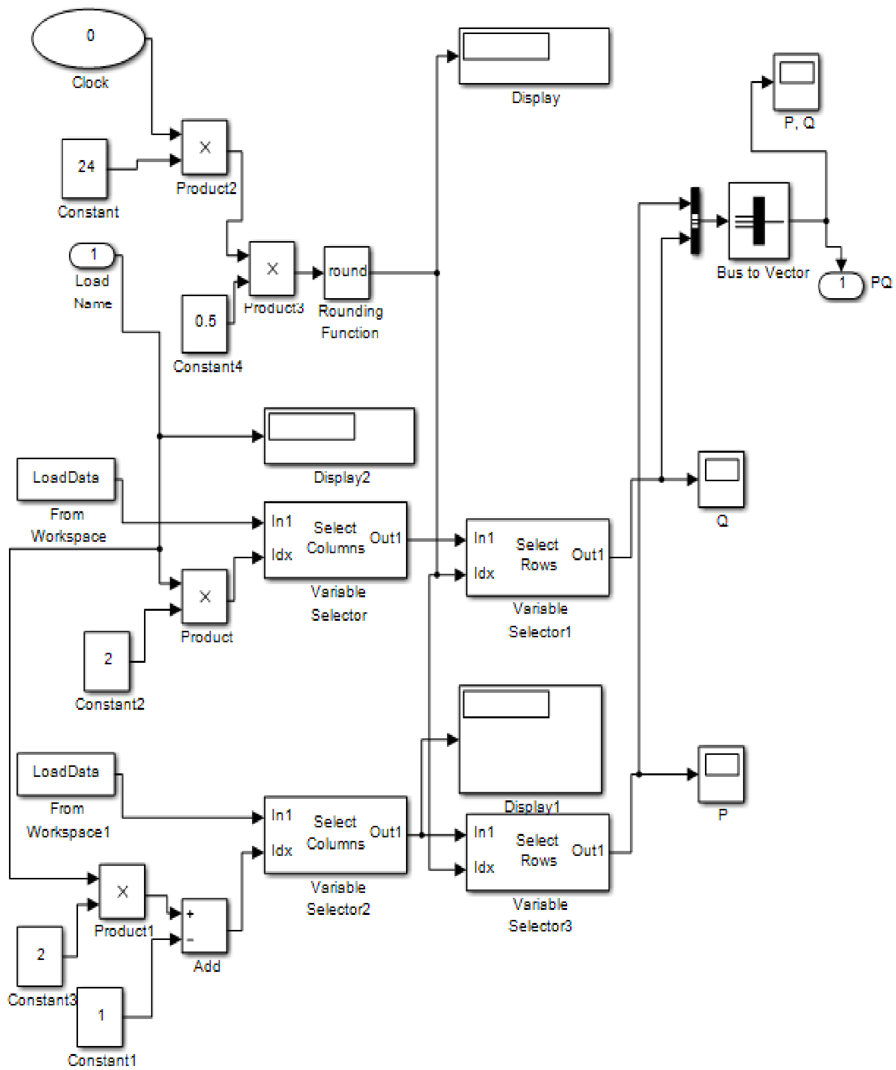


Figure 3. Active and Reactive Power Data Selection from a Spreadsheet

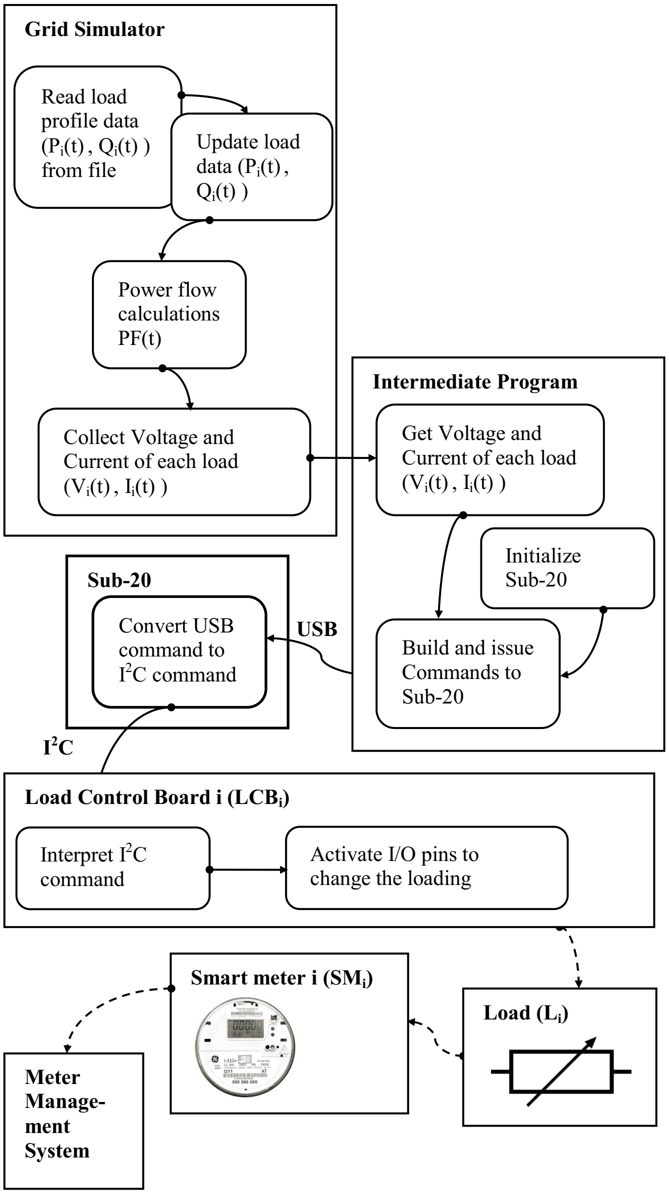


Figure 4. Overall Emulator Functionality Block Diagram

Integration with Hardware

The integration of hardware-controllable loads with the power system simulator was done via a Sub-20 USB-to-multi-protocol converter. Figure 4 shows the functional diagram of the overall emulator. Once the voltage and current data were calculated from the power system simulator, an intermediate program was used to extract these data and generate the signals that feed into the external hardware. An intermediate program generated the USB command to Sub-20, depending on the load number, i, and the voltage of load i at time t, Vi(t). Once this command was received by the Sub-20, it would convert the command to an I2C command and then send it to the I/O expander in the load control board i (LCBi). The I/O expander then turns on and off its outputs according to the I2C command, which in turn controls the voltage of the hardware load, i (Li). Figures 6 and 7 show the load control board design.

Hardware-Controlled Loads and Smart-Metering Network

Figure 5 shows the actual hardware of control boards and smart meters connected to them together with the diagram of the AMI. Figures 6 and 7 show the control board developed to interface the software simulator with the hardware loads. The controller board consists of an I/O expander, which communicates using I^{2}C protocol. The load control board uses reconfigurable potential divider techniques to control the voltage across the load resistor. Voltage can be changed between ± 5 % in ten discrete steps.

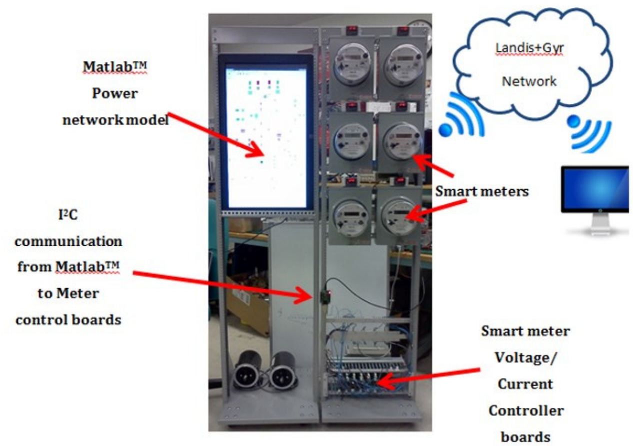


Figure 5. The Smart-Grid Emulator AMI and Hardware-Controllable Loads

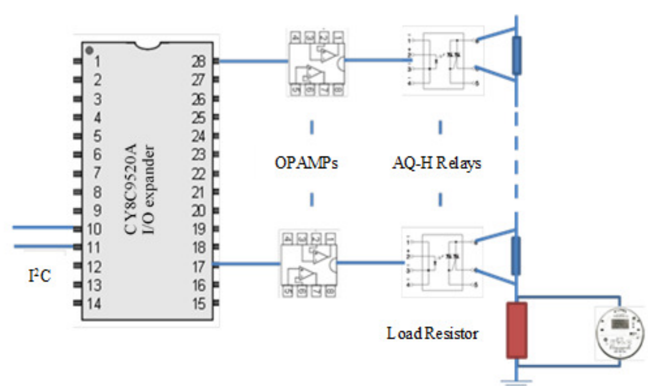


Figure 6. Block Diagram of the Controller Interface Board to Integrate the Simulator and the Controllable Loads

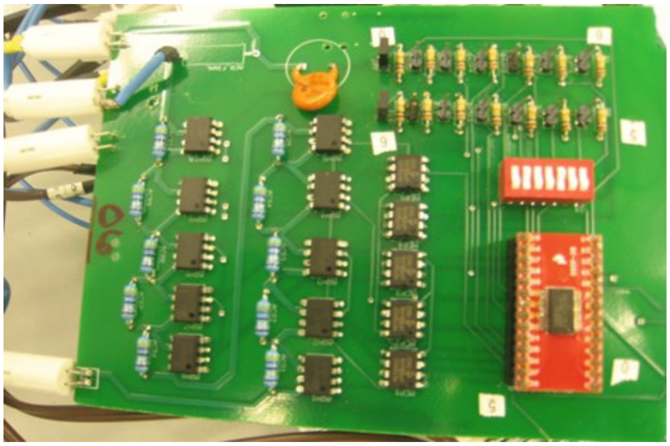


Figure 7. Controller Interface Board to Integrate the Simulator and the Controllable Loads.

Once the control signal is received from the intermediate program discussed in the previous section, the I/O expander activates the corresponding output pins. Figures 6 and 7 show how this will short some of the resistors in the potential divider arrangement. The figures also show how this change in configuration will alter the voltage across the load resistor. A smart meter was connected across the load resistor in each board, which displayed and recorded the voltage variation of the load. Smart meters communicate with the meter management system via the AMI network and record the voltage variation data. The test system consisted of six such controllable loads and their corresponding smart meters. The final system consisted of 30 such loads and was able to collect the data at critical points of a given micro-grid or selected section of a distribution network.

Proposed Current-Control Circuit

The current flow into the load resistor needed to be controlled in order to emulate the effect of active power variation. The reactive power variation was not fed into the AMI, as there were no reactive loads in the hardware system. The main idea behind the proposed emulator was to develop a simple, low-cost system to emulate the power flow in the low-voltage distribution system. The actual distribution system would have currents with higher magnitudes. The results obtained from the power system simulator gave the actual values of the current flowing into each load. If the same current were fed into the load resistors, they would need to have higher wattages. This would increase the cost of the system as well as the heat dissipation from the system.

To solve this problem, the actual current flow in the control circuit was limited to a few hundred milliamperes. The multiplier (corresponding to the current transformer) in the smart meter was set to reflect the actual current. This made the smart meter read the actual current that was equivalent to the results obtained from the power system simulator. This made the smart meter calculate its active power, which was equivalent to the power calculated in the power system simulator. Figure 8 shows the block diagram of the load control board with the current controller. With this arrangement, the smart meter can read voltage and current equivalent to the actual values in the network and then calculate the active power. This information is transferred to the meter management system via the AMI and stored for further processing.

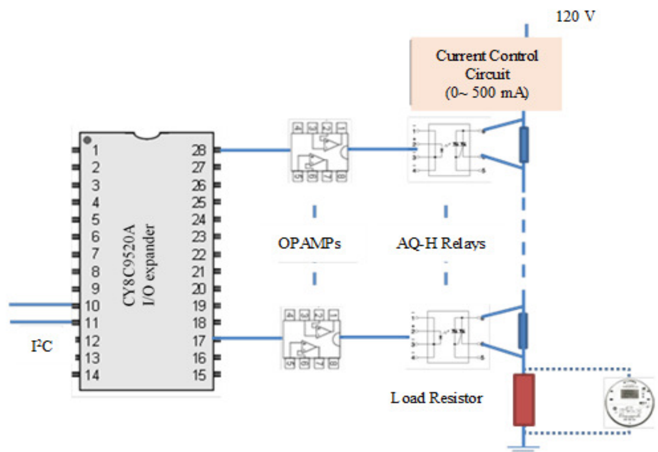


Figure 8. Block Diagram of the Controller Interface Board with Current Control

Network Model Testing and Results

Testing focused on Matlab-based simulation. Single-phase and three-phase dynamic load models available in Matlab were changed to model the time-varying loads discussed. Time-varying loads can read the load profile from the spreadsheet and change the active and reactive power demands accordingly. Table 1 shows a sample spreadsheet with load profile data. Time in column one can be adjusted according to the simulation time. Each load entry in the spreadsheet has two columns for active and reactive power in kW and kVar, respectively, under the same load name. Figure 2 shows how the Matlab Simulink model uses the LoadName data in the spreadsheet to extract the active and reactive power data. Figure 9 shows the test network created for determining the functionality of the single-phase time-varying load. Figure 10 shows the voltage, active power, and reactive power plots obtained from the single-phase load in the network with LoadName set to "5." A time-varying three-phase load used the same approach, and the results were verified for proper functionality.

Table 1. Sample Spreadsheet Containing Load Data

LOAD NAME	1	1	2	2	3	3	4	4	5	5
TIME	P	Q	P	Q	P	Q	P	Q	P	Q
0.005	4	5	1	6	2	8	2	8	-7	-303
0.01	1	5	1	6	2	8	2	8	-77	-222
0.015	4	3	1	6	2	8	2	8	-63	-103
0.02	7	6	1	6	2	8	2	8	-234	-202
0.025	7	7	1	6	2	8	2	8	-262	-466
0.03	5	2	1	6	2	8	2	8	-427	-88
0.035	7	5	1	6	2	8	2	8	-507	-11
0.04	5	6	1	6	2	8	2	8	-124	-491
0.045	2	7	1	6	2	8	2	8	-57	-30
0.05	4	8	1	6	2	8	2	8	-180	-583
0.055	6	3	1	6	2	8	2	8	-273	-120
0.06	0	5	1	6	2	8	2	8	0	-200
0.065	0	8	1	6	2	8	2	8	0	-372
A0.07	0	6	1	6	2	8	2	8	0	-334
0.075	3	3	1	6	2	8	2	8	73	-247
0.08	8	2	1	6	2	8	2	8	783	-160
0.085	6	4	1	6	2	8	2	8	3	287
0.09	3	6	1	6	2	8	2	8	253	4
0.095	4	9	1	6	2	8	2	8	315	441
0.1	0	4	1	6	2	8	2	8	0	366
0.105	3	3	1	6	2	8	2	8	104	182
0.11	9	6	1	6	2	8	2	8	120	184
0.115	4	2	1	6	2	8	2	8	292	138
0.12	6	6	1	6	2	8	2	8	360	220

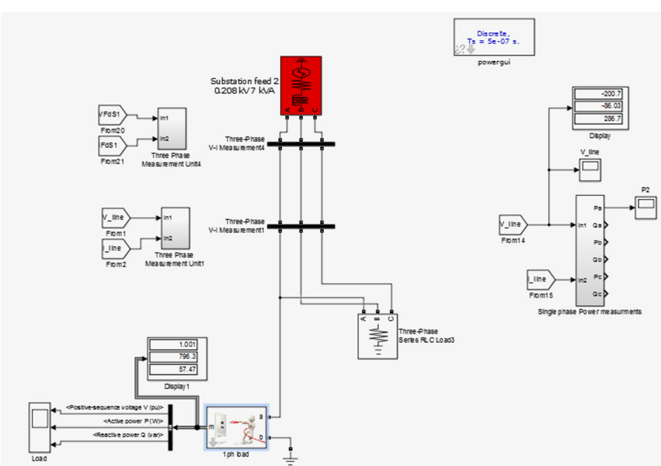


Figure 9. Single-Phase Variable-Load Test Network

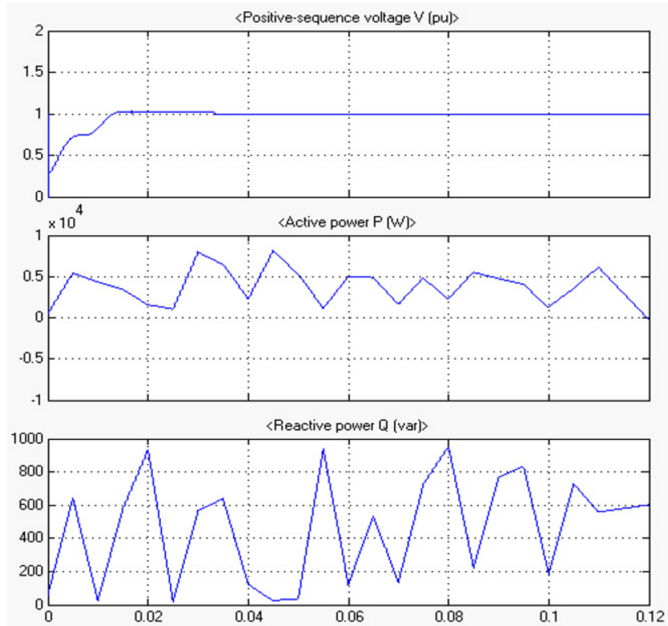


Figure 10. Results of the Single-Phase Test

Figure 11 shows the overall network that was created in Matlab for testing. The network included randomly placed DERs such as wind and solar for testing purposes. The final objective was to use MAS to find the best type, position, and sizing of the DERs in the network. Future studies on this topic will evaluate development and testing of the multi -agent system. This test network modeled 13-kV and 120V distribution systems. All of the DERs were attached to a 13-kV network, and loads were connected to 120V. Initial tests were done without connecting any DERs to the system.

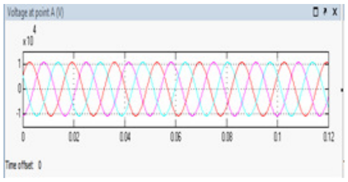
Voltage and power data were collected at different points of the network. Some of these test points include

1. Point A : Feeders of main substation
2. Point B : At the end of the 13 kV distribution line
3. Point C : At one of the three phase loads
4. Point D : At one of the single phase loads

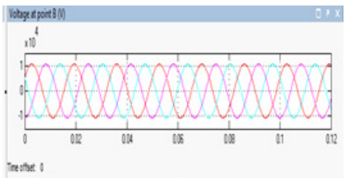
Figure 12 shows the results obtained. Figure 12(a) shows the voltage variation in 13 kV feeders of the main substation. Figure 12(b) shows the voltage variation at the end of the 13-kV line. Figures 12(c) and 12(d) show the voltage, active power, and reactive power variations in selected three-phase and single-phase loads, respectively.

Future Work and Improvement

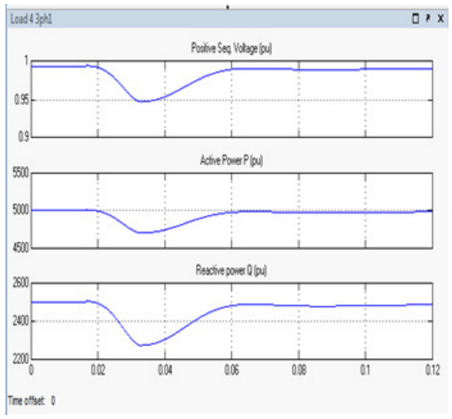
Hardware loads can be modified to incorporate reactive loads so that the AMI could see both the active power and reactive power variations. Power system control devices,



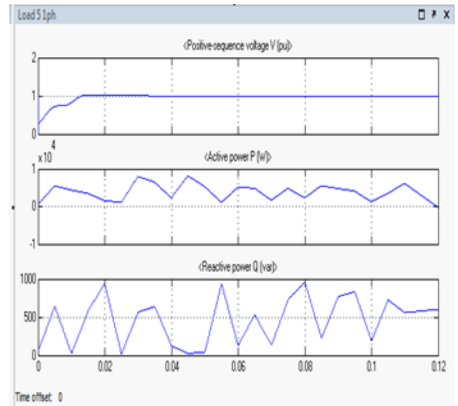
(a) Voltage at Point A in Figure 11 in Volts



(b) Voltage at Point B in Figure 11 in Volts



(c) Voltage in pu, Active Power in W and Reactive Power in Var at Point C in Figure 11



(d) Voltage in pu, Active Power in W and Reactive Power in Var at Point D in Figure 11

Figure 12. Voltage and Power curves obtained for Figure 11

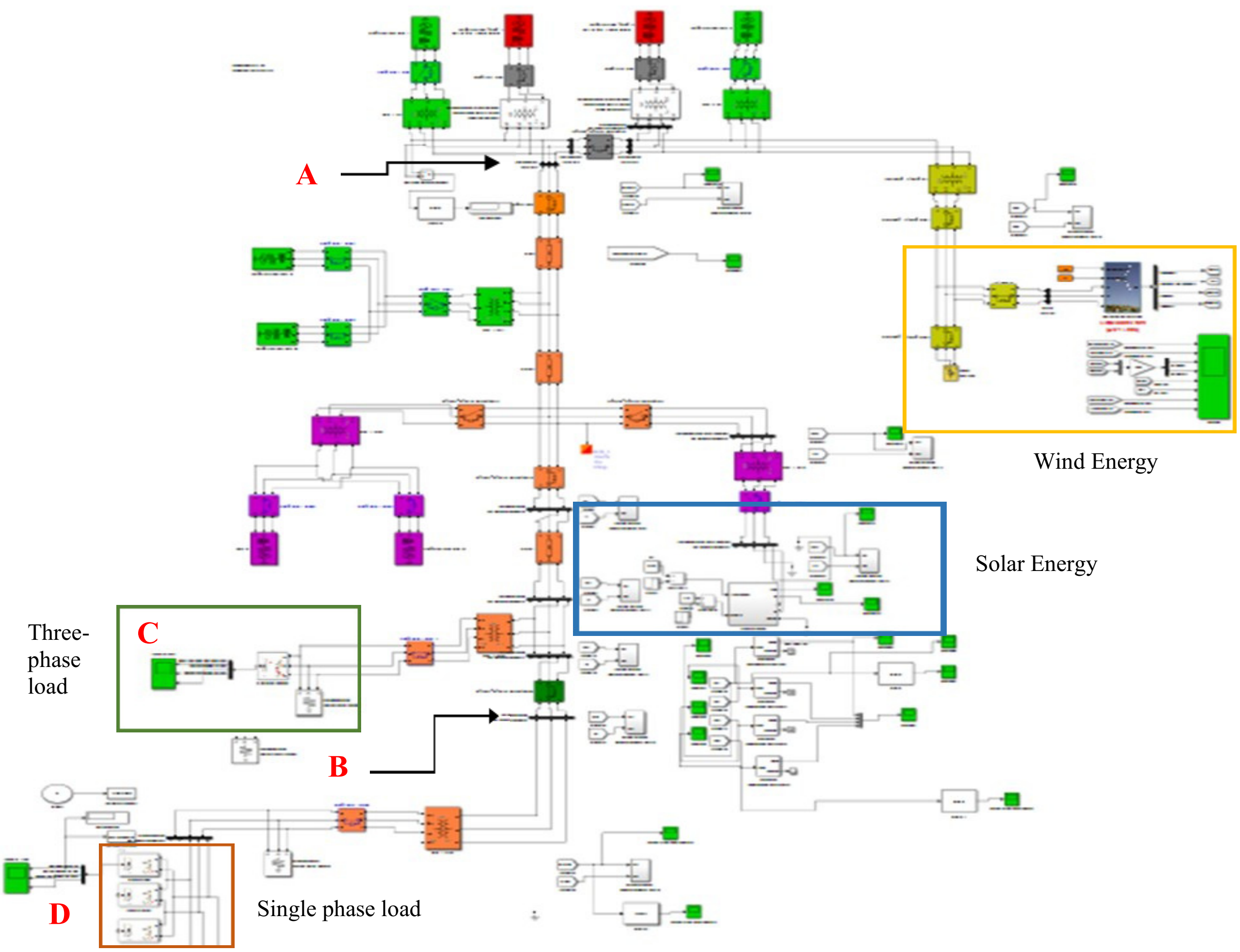


Figure 11. Overall Network for Testing

such as voltage regulators, capacitor bank controllers, and protection devices, will be installed and integrated into the same testbed. Hardware in-loop control strategies, similar to those discussed in this paper, will be used to control these devices. The total system can be used as an educational tool for students to get hands-on experience in different control and protection devices in power systems.

Conclusions

In this paper, the authors discussed a hardware in-loop emulator that can be used to study the behavior of important load points in a large-scale grid. The emulator was part of a large project that focused on developing an agent-based DER planning tool. The hardware in-loop emulator was used to emulate the behavior of the critical loads in a planned network. With future improvements, this can be used in lab environments for students to study grid stability with added DERs. Students will be able to physically interact with variable loads and associated control devices such as voltage controllers, capacitor bank controllers, and power system protection devices.

Acknowledgements

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Pathways from Community Colleges to Workforce and Academic Degrees through Stackable Certificates

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Abstract

In this paper, the author presents pathways for the graduates of associate degrees, veterans, and those who want to seek new skills to become employable through stackable certificates. This objective can be best achieved through the formation of a consortium with the local community colleges, and extending to encompass all community colleges. The introductory courses for each certificate can be offered at the participating community colleges, while the advanced courses would be offered at the university. The highlights of this program are the acceleration of skill enhancement of mid-skill workers and their re-deployment in areas of critical need to the economic development of the state and the nation. Due to the stackable format, other institutions can easily adopt the rapid portability and scalability of the program.

To this end, the University of Houston, along with consortium partners Lee College, Lone Star Community College, and San Jacinto College, agreed to develop training and educational programs to accelerate energy-related workforce development in critical areas for the state of Texas through: 1) three certificate programs, each consisting of five courses in advanced petroleum technology, advanced process technology, and advanced safety technology; 2) collaboration and articulation between consortium partners to seamlessly develop and deliver the certificate courses; 3) development of stackable credentials for students, who successfully complete any two of these certificates in an accelerated pathway (i.e., one additional year) towards a BS degree in Organizational Leadership and Supervision program at UH's College of Technology; and, 4) a competency-based survey to assess the effectiveness of the program. The proposed model can be easily developed to offer any other certificate, based on the need of a particular region and demand.

Rationale

Despite the fact that the job market fluctuates with the economy, and the demand for high-skilled and middle-skilled jobs varies for various industries and regions, the prospect for the middle-skilled jobs remains robust, especially in the foreseeable future for STEM fields. In addition, one study reported that the projected adult workers requiring bachelor's degree will grow to 33% by 2020 [1]. Middle -skilled jobs are defined as jobs that require more than a high school diploma and less than a bachelor's degree, and accounts about 48% of the jobs in the U.S. economy [2]. Among the top 30 middle-skilled jobs forecast for 2004-2018, most are in advanced technology-related jobs such as maintenance (petroleum technology certificate), computer-controlled operators (process technology certificate), and public safety (safety technology certificate). In the last 50 years, the image of well-paying skilled jobs has faded away, due to cultural shifts; thus, the demand for four-year degrees had increased. Generations X and Y do not necessarily commit to the same jobs as did older generations, and do expect to change jobs frequently [3].

Additionally, there are three factors that contribute to the need for training and certificate programs: 1) loss of jobs in major industries such as oil/gas; 2) veterans returning from wars; and, 3) constant training of a traditional workforce with the new technologies. Thus, it is imperative to develop certificate programs that address the critical needs of the current workforce and the future workforce. The concept of the proposed certificates is flexible and can be easily modified for a specific field as needed.

Joint Articulations and Collaborations with the Community Colleges

There are more than 60 community colleges in Texas that offer associate degrees in either petroleum technology, process technology, or safety technology. The majority of the graduates from the programs do not have the opportunity of pursuing a higher degree within their disciplines. Within greater Houston, there are more than nine community colleges that offer one or more degrees in petroleum technology, process technology, and safety technology. The key to the success of any joint programs with the community colleges is to develop a seamless transfer of both existing courses and certificate programs at the community colleges into a stackable advanced certificate and academic programs. To this end, the College of Technology at UH has already developed articulation agreements with most of these colleges for a seamless transfer of various programs to the college. To this end, the College of Technology at UH, in collaboration with Houston area community colleges, proposes to develop and deliver an accelerated certificate and educational programs in the following areas:

- Advanced Process Technology
- Advanced Petroleum Technology
- Advanced Safety Technology

Each certificate program will include five courses covering introductory and advanced topics for graduates with associate degrees and industry-experienced associate degree holders. Completion of a certificate, typically taking less than one year, will rapidly accelerate the employability and meeting of critical needs in middle-skilled and high-skilled areas of greatest need in the state of Texas. The courses will be developed jointly by the community college faculty, UH faculty, and part-time faculty from industry. Since the average age of the workforce in these industries (process, petroleum, and safety) is over 50 years, according to the Gulf Coast Process Technology Alliance, there will be abundant opportunities for high-skilled individuals, who successfully complete these certificates. Furthermore, successful completion of any two of these certificates provides an accelerated pathway (i.e., about a year) towards a Bachelor of Science (BS) degree in Organizational Leadership and Supervision (OLS) at the College of Technology at UH. For graduates of associate degree programs, this will provide a significant reduction and opportunity for obtaining a BS degree.

The OLS program allows transfer students to create an emphasis that is composed of at least 33 credit hours. This will provide an opportunity for those students having completed at least two of the certificate programs listed above (five courses each) to substitute 30 credit hours by successful completion of the certificate program. In addition, students would take either a project management or entrepreneurship course to meet the total 33-credit-hour requirement for the OLS degree.

Proposed Stackable Certificates

Figure 1 shows a generic model of stackable certificates, in collaboration with the community colleges is proposed. The proposed model could be offered without community colleges. However, it is recommended that a strong and sustainable program be developed with both community colleges and industry involvement. The proposed certificate courses should be developed as academic courses under a rubric such as TECH (technology) so that they can be transferred to the BS degree.

<u>Advanced Petroleum Technology</u>
TECH 3501: Fundamentals of Petroleum Industry
TECH 3502: Fundamentals of Offshore Systems
TECH 3503: Fundamentals of Pipeline Design
TECH 3504: Fundamentals of Drilling Technology
TECH 3505: Fundamentals of Geographic Information Systems (GIS)

<u>Advanced Process Technology</u>
TECH 3601: Process Design and Methods
TECH 3602: Instrumentations and Sensors
TECH 3603: Unit Operations
TECH 3604: Process Control Technology
TECH 3605: Petrochemical Process

<u>Advanced Safety Technology</u>
TECH 3701: Health Safety Environment Fundamental
TECH 3702: Health Safety Environment Systems
TECH 3703: People and Heath Safety Environment
TECH 3704: Process Safety
TECH 3705: Heath Safety Environment Capstone

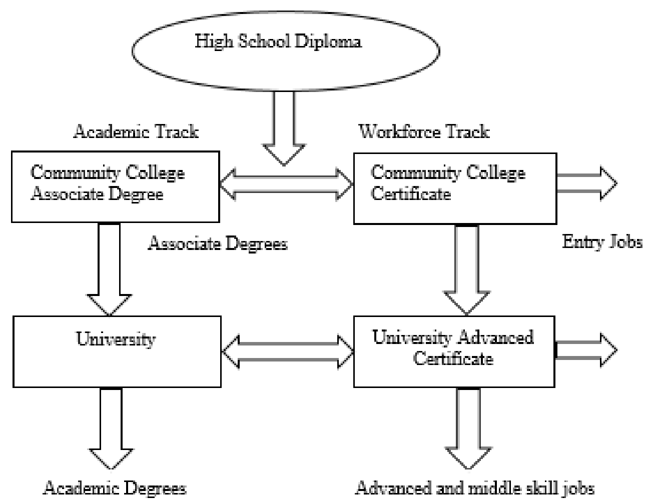

Figure 1. Proposed Academic and Certificate Programs

Each proposed certificate program consists of five courses—equivalent to one semester load of 15 credit hours. Since the courses will require the current 48-hour academic requirement, it will take 20 weeks to complete the five courses and one certificate. This is similar to one long academic semester. Thus, the proposed program will reduce the length of a one-year certificate by 50%, without compromising the quality and also providing academic credits. The 48 credit hours can be divided into about 10 hours per week (2 hours per day), or two days per week (5 hours per day). Stackable certificates are proposed in various formats in many other states [4-6]. Table 1 shows some of the existing programs at the Houston Community Colleges that will lead to the proposed advanced certificate and degree program. This will be attractive for students wanting to take another certificate simultaneously or work half time, while taking a single certificate program. As a result, the quality of the program will not be compromised, since each course is equivalent to one academic course.

Figure 2 shows the proposed certificated model with the degree requirement that leads to a BS degree in Organization Leadership and Supervision degree. As noted, it requires 11 courses, 10 of which will be credited by taking any of the two certificates. Thus, one more course is recommended, either in project management or entrepreneurship, to be added to the degree plan towards the 33 credit hours [7].

Competency-Based Assessment of the Program

A competency-based assessment will be developed for all courses in the certificate program in order to assess the effectiveness and quality of instruction. Table 2 shows a sample of such an assessment. For each course, similar competency-based assessments will be developed and implemented to measure the effectiveness the certificate programs and update and improve them as needed.

Table 1. Existing Programs at Community Colleges

Community College Degrees/Programs	Type
Instrumentation and Controls Engineering Technology	AAS and Certificate
Manufacturing Engineering Technology	AAS and Certificate
Petroleum Engineering Technology	AAs and Certificate
Process Technology	AAS and Certificate
Mechanical Technology	Associate Degree
Pipefitting Technology	Associate Degree
Process Instrumentation & Electrical Design	Associate Degree
Process Piping Design	Associate Degree
Safety Management Technology	Associate Degree
Process Technology	Associate Degree
Energy & Manufacturing	Associate Degree
Engineering Technology	Associate Degree
Safety Technology	Associate Degree

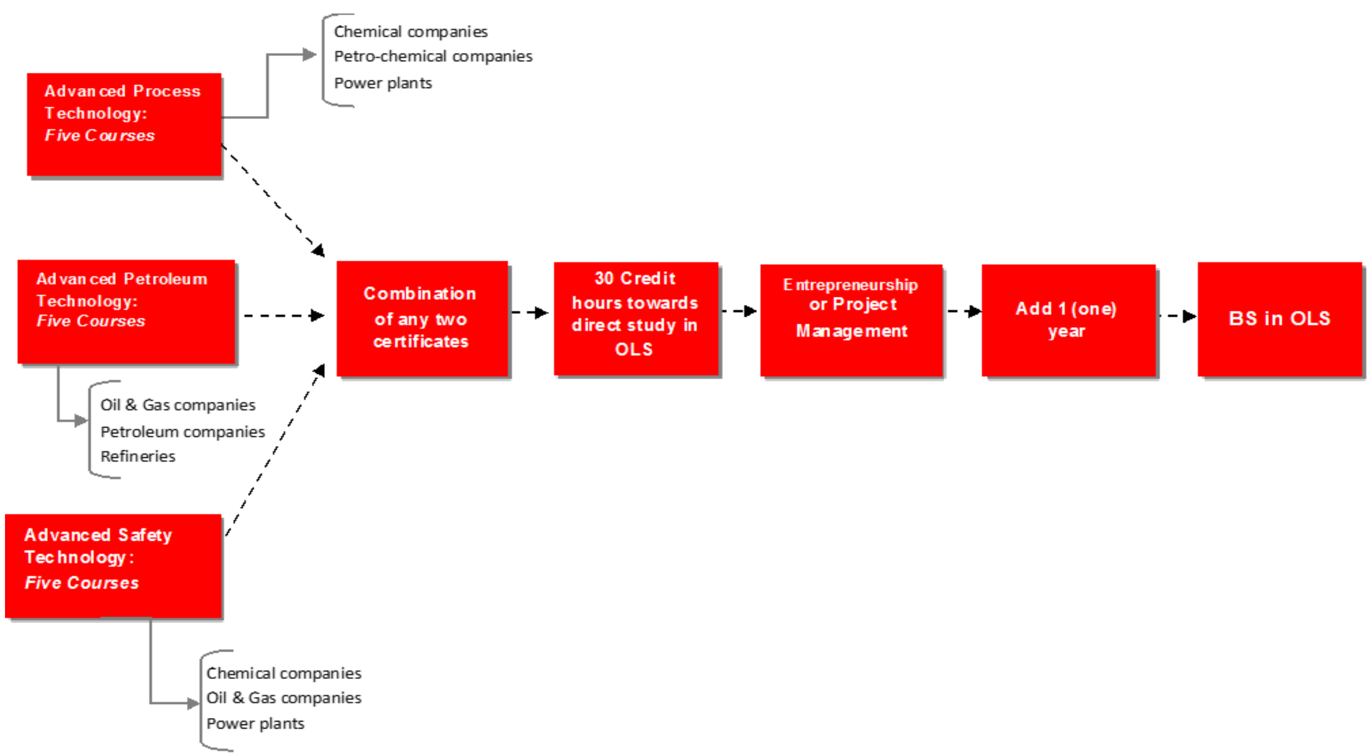

Figure 2. Detailed Model of Proposed Certificate/Education Model Leading to a BS Degree

A sample of the course learning outcomes for TECH 3604, Process Control Technology, is shown below. By the end of the course, students will be able to:

1. Demonstrate key terminology in process technology.
2. Demonstrate knowledge of automatic control and process instrumentation.
3. Describe the proportional control operation.
4. Draw and identify the components of mechanical, electrical, and chemical systems.

Topics Covered:

a. Overview of process technology
b. Process technology systems
c. Instrumentation in process technology
d. Automatic control
e. Industrial process
f. Process safety

Assessment and Performance Measures

First, the assessment of all certificate courses will begin with direct measures. Table 2 illustrates the relationship of how all certificate courses will be aligned to specific course-level learning outcomes, assignments, and assessment instruments. After each course is assessed, faculty will discuss the results reflecting student learning achievement and devise an action plan depicting ongoing results-based improvement activities. Second, the assessment of all certificate courses will contain an employer satisfaction survey (ESS) to measure employer satisfaction with certification graduates' skills and work readiness.

Conclusions

The proposed, stackable certificate program offers a unique workforce model that can be offered by any university to meet local industry needs, particularly in STEM fields. Beyond the workforce, there are additional benefits to the program. Specifically, it provides an accelerated educational opportunity for those seeking a BS degree. The lectures, which also complement the labs, enhance a collaborative student-learning environment. These additional benefits highlight how the program offers a hands-on, multidisciplinary, and experiential learning paradigm.

Acknowledgments

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Table 2. General Assessment of Certification Courses

Course	Course Learning Outcome(s)	Assignment	Assessment Instrument	Benchmark
1	Learning outcome(s) on the syllabus	Specific questions on exam(s)	Exam rubric assessing specific exam questions	70% of students must be rated "meets expectations or better" on selected dimensions of the exam assignment rubric.
2	Learning outcome(s) on the syllabus	HW Assignments	HW assignment rubric	70% of students must be rated "meets expectations or better" on selected dimensions of the HW assignment rubric.
3	Learning outcome(s) on the syllabus	Papers	Written communication and content rubric	70% of students must be rated "meets expectations or better" on selected dimensions of the written communication and content rubric.
4	Learning outcome(s) on the syllabus	Presentation	Oral presentation rubric	70% of students must be rated "meets expectations or better" on selected dimensions of the oral presentation rubric.
5	Learning outcome(s) on the syllabus	Final project	Capstone rubric	70% of students must be rated "meets expectations or better" on selected dimensions of the capstone rubric.

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Biography

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UNIVERSITY-INDUSTRY-NAVY COLLABORATION IN THE DEVELOPMENT AND DELIVERY OF AN ADDITIVE MANUFACTURING SHORT COURSE TO NAVAL PERSONNEL

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Abstract

In this paper, the authors describe a collaborative effort between Applied Systems and Technology Transfer, LLC (AST2), Francis Marion University, the U.S. Navy, and Old Dominion University's Naval Engineering and Marine Systems Institute (ODU NEMSI) to develop and deliver a short course to train military personnel on critical design thinking processes to develop innovative solutions for practical problems utilizing additive manufacturing equipment as part of the DARPA MENTOR II program. Also discussed are the curriculum, the delivery methodology, assessment, and other cooperative efforts that have grown from this partnership.

Introduction

There are many ways the U.S. Navy and U.S. Marine Corps are exploring how to use 3D printing to save time and money, both shoreside and on deployment. At the Mid-Atlantic Regional Maintenance Center (MARMC) in Norfolk, VA, and at the Marine Expeditionary Force Operations at Camp Pendleton near San Diego, CA, sailors and marines can take a broken item, create a 3D scan of the part to convert it to a computer-animated design, and then print out a reproduction of the part using a 3D printer. The printed plastic part can directly replace the broken component if it is plastic, or can be used as a prototype for a metal-printed part if the broken component is metal.

Replacing a broken component is a significant challenge for forward-deployed forces, particularly for Navy vessels that are far from shore and the nearest military installation. It may take a week or even months to locate, procure, and transport a part to the vessel, thus impacting its mission, while costing a significant amount of money to expedite fabrication and shipping. During wartime, these equipment failures and logistical support challenges can impact military readiness levels. Innovative manufacturing technologies—additive manufacturing (AM) equipment, in particular 3D printers—can alleviate a number of these concerns and make the required replacement part available on the same day. Recent efforts initiated by MARMC to equip USS Kearsarge and the USS Truman with 3D printers, and the successful part replacements completed on the USS Truman indeed demonstrate the potential of an enormous opportunity to adapt AM for design and fabrication of replacement parts, while simultaneously empowering sailors to solve challenges [1, 2]. The Navy's Print the Fleet Initiative targets the development of systems that will allow commercial AM equipment to produce required spare parts that meet specifications, including precision under the vibration, humidity, and other adverse conditions expected onboard [3].

Coupled with these potentially revolutionary advantages in shipboard readiness, the Navy faces challenges across many areas in adopting these technologies. At the forefront of these challenges is workforce development and personnel training. Although 3D printing is simple in concept, integration and adoption of any new hardware and software package can be viewed as frustrating and intimidating—oftentimes due to lack of training and support. Collaborators from AST2, Francis Marion University, the U.S. Navy and ODU NEMSI teamed together to develop and deliver a short course to train military personnel on additive manufacturing as part of the DARPA MENTOR II program. In this paper, the authors discuss the curriculum and the delivery methodology, provide student and instructor feedback, and give several examples of the course impact. Also discussed are other cooperative efforts that have grown from this partnership.

Curriculum Overview

This additive manufacturing short course curriculum introduces military personnel to critical design thinking processes to help them develop innovative solutions to practical problems utilizing AM equipment. Students learn the history and current status of AM, and explore its future uses in advanced manufacturing. Principal AM technologies are studied. Students learn and apply modeling and design applications. Students, both individually and as members of multi-disciplinary product development teams, innovate and design products and solutions to real-world challenges, evaluate their conceptual designs through an iterative process, and then create their designs through remote use of digitally controlled prototyping and AM equipment.

Section 1 of the “Design Thinking for Additive Manufacturing” curriculum guide [4] provides an introductory overview to AM. These introductory AM topics are important to convey to the students in the seminar. Regardless of the level of knowledge each student possesses, any piece of information conveyed in this section of the course can be beneficial to the students in one way or another. When a discussion on the background behind additive manufacturing took place with the students, who had some prior experience with 3D printing, many of them were still surprised to learn some of the things they didn’t know (i.e., history behind 3D printing, advantages vs. disadvantages, material properties of plastic grades, etc.). Section 2 of the guide presents 3D modeling and CAD software. This is an integral element to the AM process. Learning how to use CAD can help the user understand the comprehensive procedure behind AM, especially the why’s and the how’s behind the process. While this was not covered in-depth in the MARMC course, due to the students’ advanced capability in producing CAD models, this module should be covered to some degree. That degree will depend greatly upon the students’ overall level of knowledge on the subject matter.

Section 4 of the guide begins to delve into the design process. The design process, although not covered in the week-long seminar, is an important concept for students to learn, but many of these basic principles are somewhat intuitive. In other words, for a group of people who learn better by doing and not simply by attending a lecture, many of these principles will come naturally to them as they go through the design process. Reviewing the subject may be best suited for those needing a lecture on the importance of design before starting the actual design process through CAD; at best, thought, a little overview may be necessary for those with experience in CAD design (i.e., 10-step design process, why designs are made the way they are, etc.).

The same approach could be applied for the “design process in detail” section of the curriculum, located in Section 6. However, regardless of the knowledge level, this should be covered with all students, as this gets down to the heart of the steps behind accomplishing designs of various parts. Emphasizing the process of design through this step-by-step process of brainstorming, iterations, and the likes can help the students to both get familiar with the process as well as practice these steps to get better at design.

The use of additional tools for design purposes (Section 7) is a subject that could easily be combined with the design process lecture. The overall goal for these series of lectures is to emphasize the importance of making a good design and what steps users need to take to make that happen. While this is good information to learn, devoting a lecture to properly ranking each design factor may be excessive for this seminar course, adding unnecessary steps to learning about the importance behind the design process, depending on experience of the students.

As covered in Sections 9 and 11 of the guide, the different types of AM techniques are very important and interesting to convey. The instructor went over these techniques with the MARMC students and they were very intrigued by the information shared. It is believed that, due to the widespread applicability of 3D printing—from biomedical to aerospace applications—this increased the students’ curiosity about the subject. Additionally, this lecture covers the steps the maker will perform in preparing a part for 3D printing, as well as its advantages/disadvantages and the different types of AM techniques that exist. This level of exposure oftentimes inspires creativity and self-learning to access resources beyond what is readily available in the course. Prior to the course, the students had used their knowledge to build small demonstration parts from plastic using their printers. Figures 1 and 2 show some examples of the kinds of parts they possess the capability to make.

Figure 1. Plastic Screw

Figure 2. Chess Piece

Projects to reinforce the learning modules are incorporated in Sections 3, 5, 8, 10 of the course material.

Course Delivery

The course was delivered to military personnel in two different settings: a weeklong seminar at the Mid-Atlantic Regional Maintenance Center (MARMC) in March of 2016, and a week-long seminar at the Marine Expeditionary Force Operations at Camp Pendleton near San Diego, CA, in April of 2016, which focused on 3D printer assembly and operation. The purpose behind the instruction is to familiarize military personnel with critical design thinking processes to develop innovative solutions for practical problems utilizing AM equipment and to prepare them to successfully pass on the instruction to other personnel, thus a "train the trainer" concept of instruction. This is the first time MARMC and USMC have hosted a course of this nature.

During the weeklong seminar conducted by ODU and AST2, the objective was to build the students' competency in order to perform hands-on tasks using their INVENT3D printers. As part of the course, students became familiar with its features and assembled all parts of the printers. Figure 3 shows a picture of the INVENT3D printer [5]. The INVENT3D printer overview [5] consists of the following teaching components:

- Overview of 3D Printers
  - Summary of How 3D Printers Function
  - Detailed Discussion of How 3D Printers Function via Firmware Printer Control Software
- Characteristics and Function of INVENT3D Printer Components
  - Fasteners
  - Motors and Drives
  - Printer Box
  - Printer Control and Software
  - Print Head
  - Print Bed

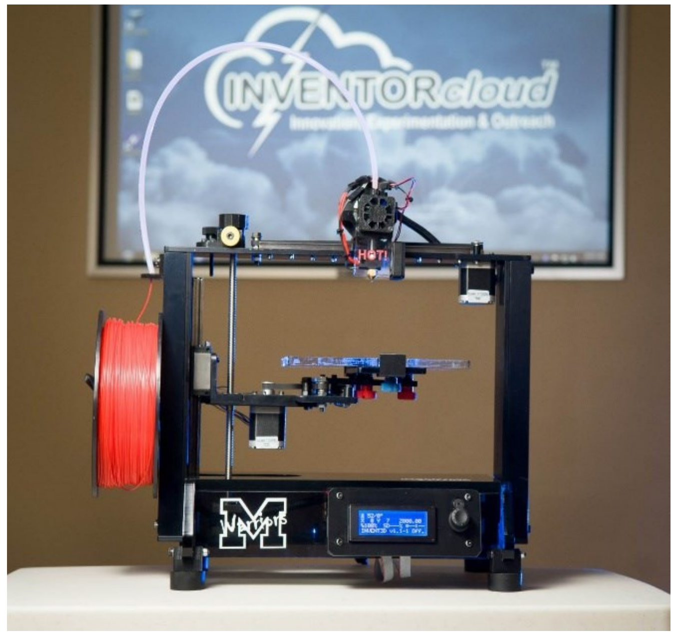

Figure 3. INVENT3D Printer

Table 1. Student Assessment for USMC Short Course

		Highly Disagree	Disagree	Neither Agree nor Disagree	Agree	Highly Agree
1	The course was well organized.	0	0	0	84%	16%
2	The course gave a good introductory overview of additive manufacturing.	0	0	0	33%	67%
3	The topics covered in this course are relevant to my job.	0	0	0	33%	67%
4	The course objectives met my training needs.	0	0	0	33%	67%
5	The activities used in the course were appropriate and helped me to learn.	0	0	0	16%	84%
6	The instructor was knowledgeable on the subject.	0	0	0	0	100%
7	The instructor presented the material clearly and understandably.	0	0	16%	50%	34%
8	The course materials were presented on an appropriate level for the introductory course.	0	0	0	33%	67%
9	Overall the course was valuable to me.	0	0	0	0	100%
10	I would recommend this course to my colleagues.	0	0	0	0	100%

ODU and AST2 mentored each student through assembly of the INVENT3D desktop printers (from motor assembly to filament loading). Three printers were set up in teams consisting of 2-3 students each.

Course Assessment

Students from each course were asked to complete a post-assessment survey. Feedback on the short courses was overwhelmingly positive. Tables 1 and 2 highlight the results from the USMC and MARMC short courses.

Impact on Navy

Sailors with little to no previous experience in AM, all of whom were from non-manufacturing backgrounds, were trained on INVENT3D and 3D CAD design and engineering concepts during the short course. During the training, sailors readily mastered the AM and CAD concepts. Following the training, sailors applied those concepts to achieve several innovative projects to design, build, and implement replacement parts that improved operational performance and achieved cost savings. As an example, sailors onboard the USS Truman developed the Tru Clip design. The Tru Clip design, shown in Figures 4 and 5, is a simple 3D-printed device designed to fix broken handheld, shipboard radios. According to the Navy, the existing radio clasp was a common failure point and cost the Navy $615 for each replacement piece. The Tru Clip was manufactured using the INVENT3D printer and has saved the Carrier over $40,000 in six months, with a potential to save over $1M per year after fleet-wide application [6].

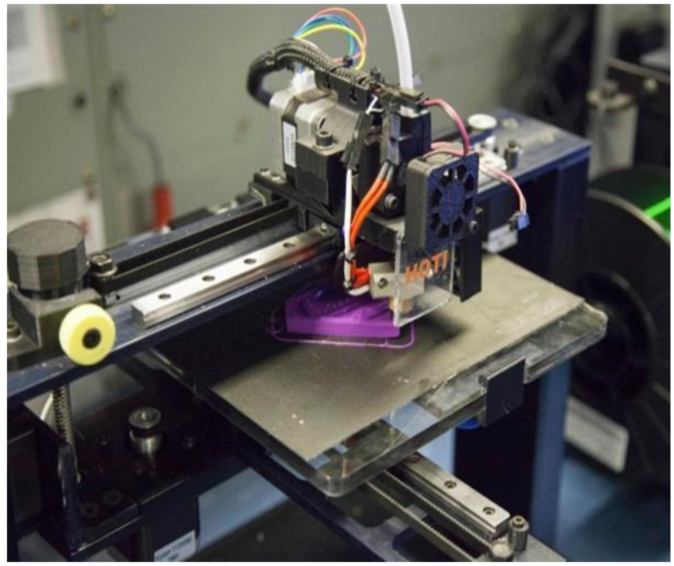

Figure 4. INVENT3D Printing a Tru Clip onboard the USS Truman [6]

Examples of other designs developed, manufactured, and used include non-procurable items as well. Figure 6 shows a second example of printing plastic housing for pigtail adapters on Combat systems that were constantly cracking and could not be replaced without reordering the complete part; this resulted in average monthly savings of $8000 and has Navy-wide application for significant savings. Figure 7

Table 2. Student Assessment for MARMC Short Course

		Highly Disagree	Disagree	Neither Agree nor Disagree	Agree	Highly Agree
1	The course was well organized.	0	25%	0	75%	0
2	The course gave a good introductory overview of additive manufacturing.	0	0	25%	50%	25%
3	The topics covered in this course are relevant to my job.	0	0	0	75%	25%
4	The course objectives met my training needs.	0	0	0	100%	0
5	The activities used in the course were appropriate and helped me to learn.	0	0	25%	75%	0
6	The instructor was knowledgeable on the subject.	0	0	0	100%	0
7	The instructor presented the material clearly and understandably.	0	0	25%	75%	0
8	The course materials were presented on an appropriate level for the introductory course.	0	0	50%	25%	25%
9	Overall the course was valuable to me.	0	0	0	100%	0
10	I would recommend this course to my colleagues.	0	0	0	100%	0

shows a third example: a throat guard that readily fits the ship's nitrogen purge kit, thus preventing a work stoppage in excess of 7-10 days to acquire the same fitting from an off-ship supplier.

Figure 5. Tru Clip in Use onboard the USS Truman [6]

Figure 6. Hydra P7100 Housing Adapter

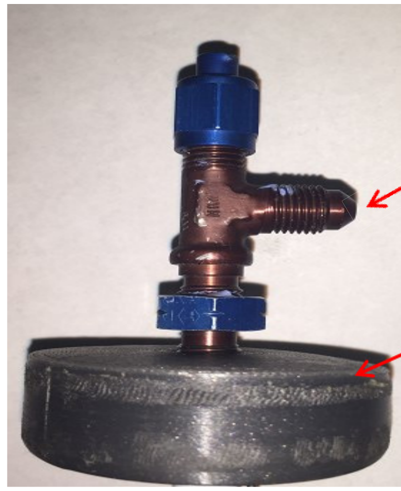

Figure 7. Nitrogen Purge Kit Fitting for F/A-18 Maintenance Team

Impact on USMC

Marines at Camp Pendleton and Camp Lejeune attended a 2-day training workshop on INVENT3D printer use and design. Within days after training, Marines started designing and producing much-needed replacement parts. A few examples include

- A critical part of the amphibious attack vehicle (see Figure 8) was designed and manufactured in one day; the part would have taken over 200 days to procure through normal processes, thereby improving operational readiness by over 199 days.
- Numerous items for amplifier units, such as those shown in Figure 9, were designed and produced within hours at a cost of 2-25% of supply cost, which considerably reduced procurement delays.

Figure 8. Power-Take-Off Yoke Shifter Replacement Part for AAV

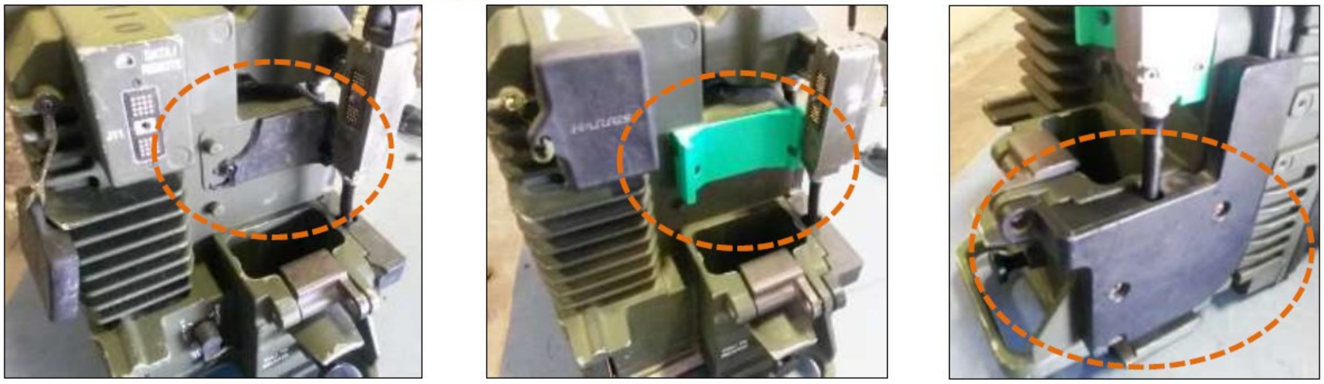

Figure 9. AN/VRC 110 Vehicular Amplifier Unit Replacement Parts

Recommendations for the Future

The course curriculum provided a very good outline on what can be covered in an additive manufacturing short course. However, the course outline is subjective, depending on the experience level of the students. Before the instruction, the experience level of the core attendees of the course should be assessed so that the lesson plans can be crafted accordingly. In general, all of the lesson plans discussing the design process should be consolidated into one lesson plan (Sections 4-8). The lesson could begin by going over the design process as well as briefly reviewing different procedures that are traditionally used in design.

Since AM mainly focuses on the physical aspects behind building parts from the ground up, the hands-on aspect should continue to be emphasized throughout the course. Students should also look at industrial-based printers used in academia and industry. This would allow the students to obtain well-rounded knowledge on the advantages, disadvantages, and appropriate uses of different AM techniques. Since students are mainly able to obtain knowledge "by doing," the course should continue to emphasize project-based learning pedagogy.

The lesson plans listed in the curriculum, such as introduction to additive manufacturing, CAD and model conversion, and different forms of additive manufacturing, should remain in the course. The instructor observed that the students were enthusiastic when they learned about these processes, since they related to what the students were doing. Also, allowing the students the freedom to design in CAD and understand their 3D printers as they wished increased their comfort-level with the course. The INVENT3d instruction manual was in draft form at the time of the MARMC seminar. Feedback on the manual was valuable and will be incorporated into the final draft of the instruction manual.

Other Cooperative Efforts

Other cooperative efforts that have grown from this dynamic partnership are outlined below.

- Under DARPA's MENTOR program, distributed design and manufacturing technology integrating 3D printers and other subtractive equipment was developed. Also developed was a virtual rapid-prototyping laboratory used by thousands of students for learning the concepts of developing design solutions and producing items using 3D printers available through INVENTORcloud.
- Additionally, a rugged and inexpensive printer, INVENT3D, was developed; over 200 of the printers were manufactured and deployed in over 100 schools, Army and Navy installations, and on two Navy vessels. Sailors developed practical solutions, developed designs, and fabricated and utilized numerous solutions that saved the U.S. Navy thousands of dollars [6].
- INVENT3D printers were integrated into MARMC's fab lab and used to train sailors in design thinking and additive manufacturing to develop problem solving skills.
- Miniature fab labs, consisting of INVENT3D printers, were deployed; work stations and a desk top CNC machine were deployed on two U.S. Navy ships.
- Collaborating with SPAWAR and USMC at Camp Pendleton, Marines assembled INVENT3D printers in fewer than three hours, and designed and manufactured parts in less than one week after training. Commercially available technologies were designed for use in laboratories and plants under controlled and stable (stationary) conditions. Their adoption by the Navy and USMC may present some challenges, due to the shock, impact, and vibration forces experi-

enced onboard Navy vessels. Additionally, large commercial printers are designed to achieve 'capacity' for production plants. Military applications, though, require rapid-prototyping capability for unique applications, as opposed to production capacity; thus, smaller and more flexible printers may be more appropriate.

Conclusions

3D printing in recent years has caught the attention and interest of the U.S. Navy. There are many ways the U.S. Navy and U.S. Marine Corps are exploring how to use 3D printing to save time and money both shoreside and on deployment. In this paper, the authors described the collaboration between Applied Systems and Technology Transfer, LLC, (AST2), Francis Marion University, the U.S. Navy, and Old Dominion University's Naval Engineering and Marine Systems Institute (NEMSI) to develop and deliver a short course to train military personnel on critical design thinking processes to develop innovative solutions for practical problems utilizing additive manufacturing equipment as part of the DARPA MENTOR II program. Also discussed were the curriculum, the delivery methodology, and assessment. The outcome of the efforts to-date reinforce the team members' confidence that, with good training and inexpensive equipment, 3D printing can have a significant impact and provide great returns. Parts can be made when and where needed to improve operational readiness, as demonstrated by both U.S. sailors and U.S. Marines.

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Biographies

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JACK SCOTT is founder and president of Applied Systems & Technology Transfer, LLC (AST2). AST2 provides technology solutions and professional services to government and commercial clients. He has developed INVENTORcloud, which creates a virtual learning and collaboration environment by integrating hardware capabilities, software applications, and a dynamic curriculum for use in secondary, post-secondary, and industry settings. He designed the INVENT3D printer, which is manufactured by AST2 with secondary and post-secondary students participating in a work-based learning program. Mr. Scott concluded a successful career with Parsons, an international engineering, design, technical services, and construction firm with over $4 billion in revenue and 14,000 employees as president and COO. He was responsible for all aspects of operations of one of the world's largest engineering and construction companies, executing mega-projects in infrastructure and defense. Prior to Parsons, Mr. Scott had a successful career with the US Army Corps of Engineers and the program manager for Chemical Demilitarization. He is chair of exp.federal, which provides U.S. federal clients best-in-class services in the architecture, engineering, operations & maintenance, and mission critical support services domain. Mr. Scott has been a leader in promoting collaboration between industry and academia. Mr. Scott serves on the Youngstown State University President's Council, as well as the YSU STEM Council. He also serves on both the Industrial Engineering and School of Engineering advisory councils at Texas A&M University. He earned numerous awards and recognitions from universities and professional organizations including the Captains of Industry Award, Institute of Industrial Engineers. Mr. Scott earned an ME in Industrial Engineering from Texas A&M University. Mr. Scott may be reached at john.a.scott@ast2.net

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Do Certifications Make a Difference in the Recruitment of Graduate Students for Industrial Management Programs?

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Abstract

The goal of most institutions of higher education is to provide their students with a general understanding of the subject matter so they can eventually adapt to a variety of jobs related to their career fields. In contrast, many companies review résumés for management-related positions, looking to find the best qualified applicants having a documented track record of their knowledge and accomplishments through specific certifications and/or professional licensures. In this paper, the authors discuss the perceptions of graduate students regarding the importance of earning certifications while earning a degree. In addition, while addressing this issue, the authors also provide the details of how a dying graduate program was revitalized into one that is sought after by students from across the globe.

Introduction

Over the years, it has been common for many technical areas to certify their practitioners [1, 2]. Automotive technicians, nurses, welders, electricians, computer support specialists, and others are required to be certified or they often cannot legally practice their profession or trade. Typically, certification requires practitioners of the profession to demonstrate that they possess a minimum body of knowledge, and it may also require a pledge to follow an ethical code of conduct [3, 4]. According to Gilhooly [5], company-subsidized training and certification for an organization's staff are not just perks but a necessity for ensuring quality. Furthermore, certifications can be valuable tools for hiring and retaining employees [6]. Many IT departments and a company's overall business performance for that matter can reap such benefits as increased productivity and improved information system performance, when staffed by certified professionals [7-9].

As the cost of a college education continues to escalate and saddle students with debt, more and more individuals are debating the merits of earning a certification or a graduate degree [10-12]. According to Dwyer [13], "certificates are the fastest growing form of postsecondary credential around." Furthermore, a report from the Georgetown University Center on Education and Workforce [14] noted that, "In 1980 only 6 percent of Americans earned a certificate, but that's skyrocketed up to 22 percent, with more than one million of us earning a certificate every year."

Purpose of the Study

As the number of personal certifications continues to escalate, the question arises as to whether academia should deem it necessary to offer more certifications to students? Although most business and industry professionals agree that certifications are important to advancing their careers, this study was conducted to see if offering certifications had any effect on a graduate student's decision on declaring a major. More importantly, did incorporating certifications that could be counted towards coursework for a graduate degree become a major factor in the selection of a graduate degree?

Methodology

In the fall semester of 2006, the Department of Technology at The University of Texas at Tyler had only one student enrolled in the graduate program, and was notified by the Texas Higher Education Coordinating Board that the program would be closed if it could not graduate fifteen students in five years. The program coordinator quickly reviewed similar graduate programs that had shown growth, as illustrated in past NAIT Industrial Technology Program Directories from 2000-2004 [15-19]. In addition, the program coordinator asked the remaining student in the program what he wanted out of the program and if he would be interested in the curricula offered in other programs that showed growth in the NAIT Industrial Technology Program Directories. There was a consensus that adding lean and six sigma quality to the curricula would attract more students.

Once the new curriculum was approved and offered the following year, 12 new students entered the program and the enrollment continued to grow until it plateaued for several years. In order to determine the reason for this stagnation in enrollment, students were queried informally during classes to determine if there was anything else the students wanted from the program. Several students noted that it would be nice if they could be Lean Six Sigma Black Belt certified, since the program covered most of the content on currently available certification exams. Once this certification was finally approved and advertised, the program began to increase its enrollment. Furthermore, more students inquired about other certifications they would like to pursue. Each year, additional certifications were integrated into the program's degree plan, and faculty were sent for training to properly prepare them to effectively deliver the curriculum to students. Before going any further with more certifications, the faculty of the program wanted to make sure that certifications were a useful recruitment tool for students, since they had to spend a lot of time training and preparing the new coursework required by the certification. A 10-question survey was then prepared by the faculty to query the students regarding the topic of certifications.

Results

The following 10-question survey was developed by the Department of Technology faculty and was administered to a total of 132 industrial management graduate students in order to obtain their perceptions regarding certifications. There were 115 surveys that were properly completed for a total response rate of 87%. The length of the survey was limited to 10 questions in order to increase the response rate [20]. In addition, respondents were told to read all of the questions first before answering any of the questions. In an additional effort to increase the response rate, students were also given bonus points towards assignments if they filled out the survey. The first question on the survey dealt with the impact of allowing students to count coursework for three certifications towards their degree. Figure 1 shows that 50 out of 115 respondents listed that option as the main reason for majoring in the program. Additionally, 55 students listed that benefit as either the second most important reason or one of several reasons for earning a degree from the program. In all, 91% of the respondents agreed that earning certifications while earning a degree was one of the reasons they chose this degree.

The second question on the survey was concerned with how well the students liked the curriculum content of the program. Figure 2 shows that all but three of the students (97%) felt that it was a reason why they selected their field of study. Fortunately, none of the respondents felt that the content of the program did not affect their decision. Figure 3 indicates the respondents' perceptions towards each certification being offered in the program; 30 respondents noted that the Lean Six Sigma Black Belt certification was the main reason for them majoring in industrial management. Moreover, 110 of the 115 respondents (96%) felt that it was one of the reasons they were majoring in the program or, at the very least, thought of it as an added bonus.

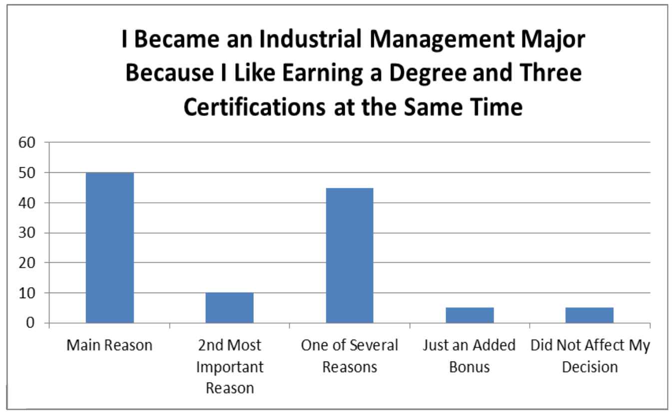

Figure 1. Student Response to Earning a Degree and Certifications Simultaneously

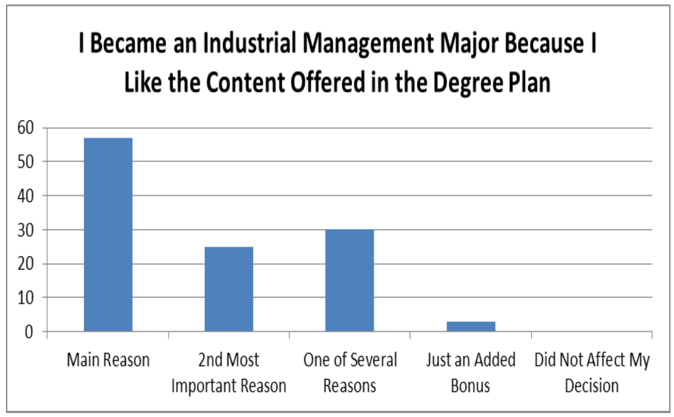

Figure 2. Student Response to Content in the Degree

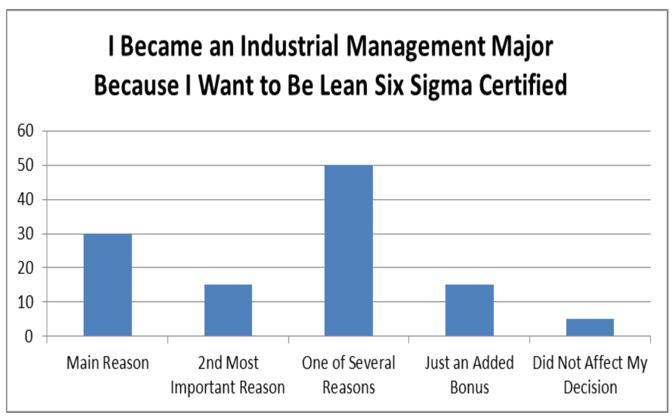

Figure 3. Student Response to the Lean Six Sigma Black Belt Certification

Figure 4 shows the fourth question on the survey, which focused on whether students wanted to become Supply Chain Management certified. It was interesting to see that approximately the same number of respondents chose this certification as one of their reasons for becoming an Industrial Management major as the Lean Six Sigma Black Belt certification, 76% to 83%, respectively. However, six other respondents selected the Supply Chain Management certification as their main reason for enrolling in the program. On the other hand, 19 respondents noted that the Supply Chain Management certification did not affect their decision to major in the program, while only five respondents noted this for the Lean Six Sigma Black Belt certification.

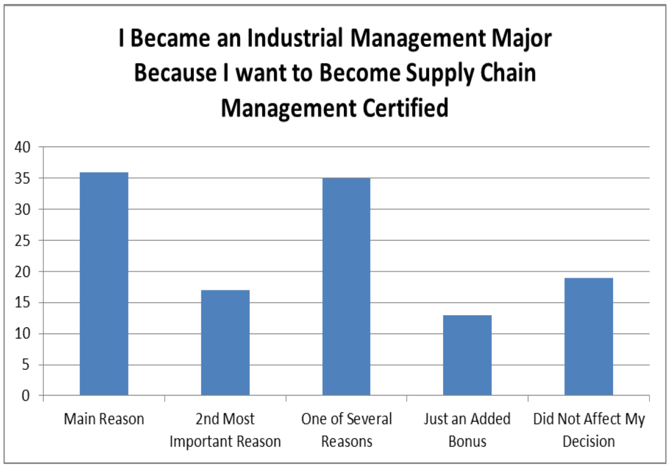

Figure 4. Student Response to the Supply Chain Management Certification

As project management certifications have risen over the years, especially through organizations such as the Project Management Institute (PMI), it was interesting to see that even Industrial Management majors were aware of its importance (see Figure 5) [21]. In fact, 20 of the respondents listed this certification as their main reason to enroll in the program, and over 85 (74%) of the respondents selected it as one of several reasons for becoming an industrial management major, or at least as an added bonus. Oddly enough, none of the respondents chose it as their second most important reason for selecting this major.

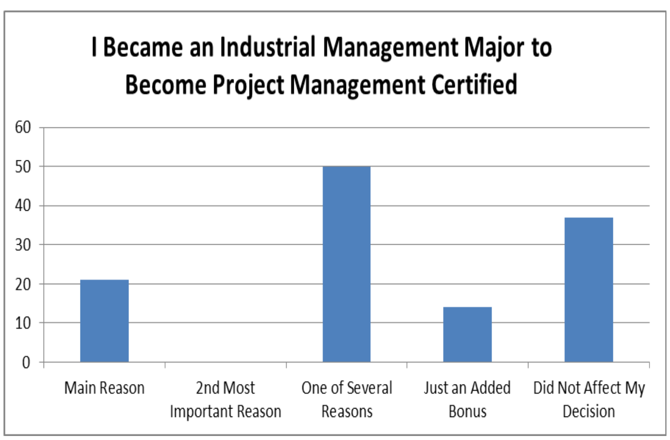

Figure 5. Student Response to the Project Management Certification

The sixth question on the survey that pertained to FANUC robotics certification seemed the most intriguing of all the certifications. A few years ago, it was felt that specific skills training, such as programming a particular type of robot, seemed to be better situated at the associate or baccalaureate level. Furthermore, the faculty thought that the entire course on computer integrated manufacturing would be a better fit for just the undergraduate Industrial Technology program that was offered by the department. Contrary to the opinions of the faculty in the department, the FANUC robotics certification had generated the most interest of all the certifications. As illustrated in Figure 6, 56 of the respondents chose the FANUC certification as their main reason for majoring in industrial management. Additionally, only four of the respondents noted that it did not affect their decision to enroll in the program.

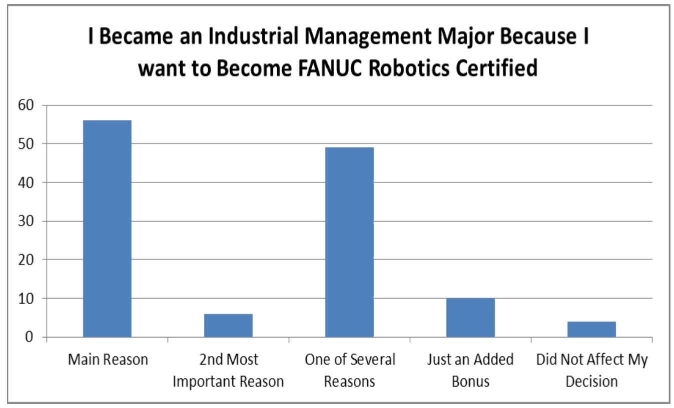

Figure 6. Student Response to the FANUC Robotics Certification

Question 7 was concerned with whether or not friends influenced what a student would chose as a major. More specifically, would a student select a major just because his or her friend was enrolled in the major? Figure 7 shows that, luckily, none of the respondents listed that as their main reason for majoring in industrial management with a whopping 91 (80%) of the respondents selecting the answer, "Did Not Affect My Decision." The authors welcomed this response from the respondents, because it was expected that at this stage in a student's life they were not affected by peer pressure and were more concerned with preparing for their future careers and livelihood.

Figure 8 illustrates Question 8 and notes that only 20 out of 115 majors primarily enrolled in the program for its reputation and excellent job placement record. Figure 1 shows that although almost all of the respondents listed that as one of their reasons for becoming an industrial management major, more (50 respondents) selected earning a certification along with their degree as the main reason for becoming an industrial management major.

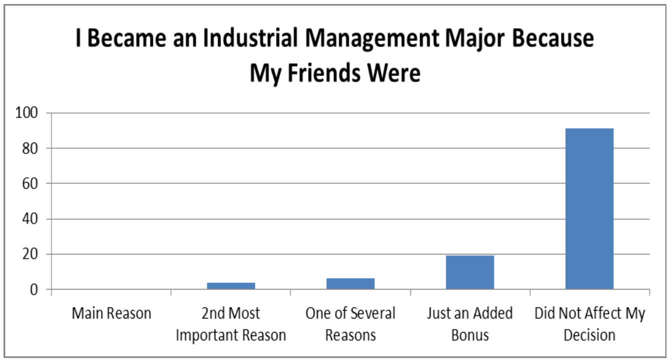

Figure 7. Student Response to Friends Enrolled in the Program

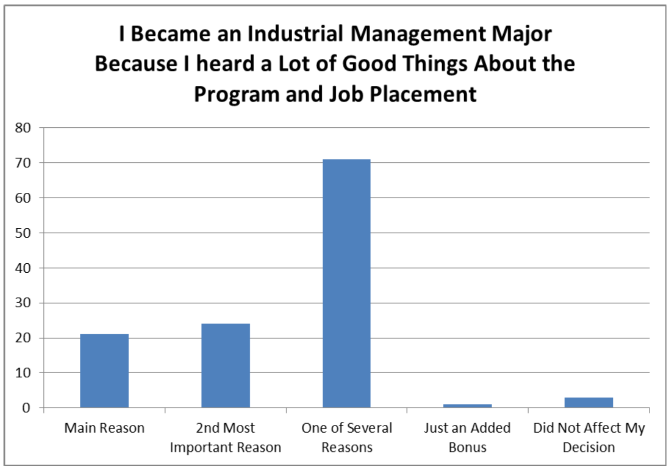

Figure 8. Student Response to Program Reputation and Placement

Fittingly, in survey Question 9, 96 (83%) of the respondents chose industrial management as their major because they wanted to be an industrial manager. Figure 9 shows that 19 of the respondents noted that it did not affect their decision to select this major.

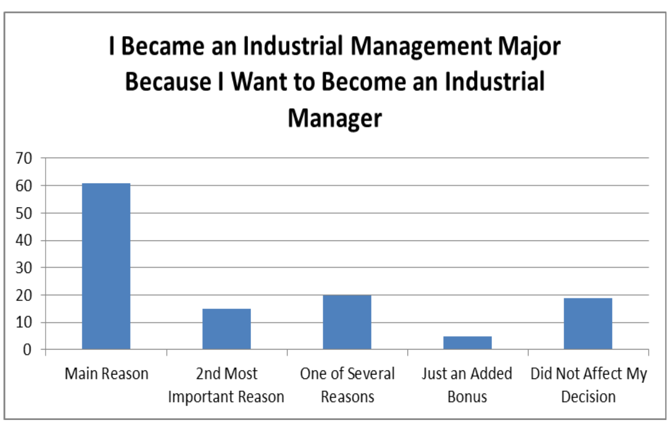

Figure 9. Student Response to Becoming an Industrial Manager

The last question on the survey asked the respondents if they believed that certifications were critical to obtaining a position in a difficult job market. Figure 10 shows that 66 of the respondents believed that that was the main reason for enrolling in the Industrial Management program, which was the highest total for that answer on the survey. As a whole, 112 (98%) of the respondents noted that it was one of the reasons they enrolled in the program; none of them chose the answer, "Did Not Affect My Decision."

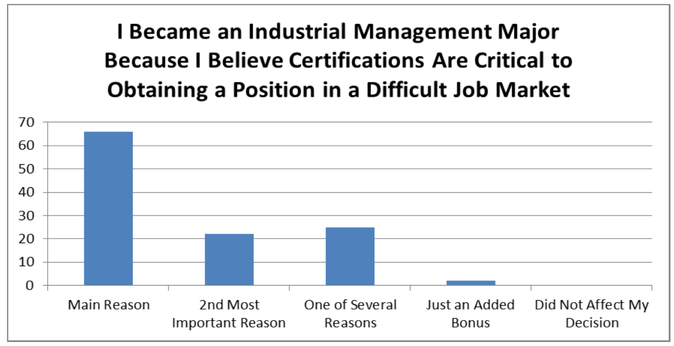

Figure 10. Student Response to the Importance of Certifications

Conclusions

As illustrated by the responses to the survey, almost all of the 115 graduate students felt that certifications were critical to obtaining employment in a difficult job market. Furthermore, 83% of those queried felt that obtaining certifications that count towards the degree requirements was an important reason why they majored in the Industrial Management program. Moreover, for each of the four certifications listed, over 50% of the respondents noted that earning one of the certifications was one of the reasons why they enrolled in the program. It should also be noted that, as additional certifications had been introduced into the program, the number of students enrolled in the program had increased accordingly. Additionally, students majoring in MBA, engineering, industrial psychology, or other subjects have enrolled in the industrial management courses in order to obtain certifications. It can, therefore, be concluded that certifications are not only attractive to technology-related majors, but majors from a variety of disciplines at the graduate level.

In conclusion, after 10 years of revising the curriculum and adding certifications to the Industrial Management curriculum, the program has grown from one student to well over 100. In essence, a program once marked for termination is now thriving and is also internationally renowned by adding industry-recognized certifications to the program's curriculum.

Limitations

It should be noted that the population queried for this research was only from one Industrial Management program from the U.S. The survey instrument was created on the premise of extracting information regarding current student perceptions of the certifications offered by the program, and if there was a direct correlation with their offerings and the increase in the growth of the program. Furthermore, the survey instrument was reduced to only 10 questions in order to obtain an adequate response rate. The survey instrument was not developed following the standardized rules for creating surveys and questionnaires, as noted by many experts in the field [22-24].

Recommendations

This survey should be conducted annually to continue to gain insights into graduate student perceptions. In addition, the questions may be better interpreted with less ambiguity by using a five-point Likert-type scale. It was noted on some of the surveys that respondents selected the answer "Main Reason" for most of the answers, which should have only been used once. Likewise, a question should be added to ask the respondents to list any other certifications that they would like to obtain while earning a degree. Also, there should be a follow-up question for those respondents, who did not select becoming an industrial manager as a reason for majoring in industrial management, in order to see what their career aspirations are. Furthermore, maybe more questions not pertaining to certification should have been included in the survey to prevent unwanted bias towards the importance of certifications. It should also be noted that the voice of the customer was an important tool in the continuous improvement process illustrated in the upward enrollment trend with this program and could, therefore, be a topic for further study.

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New Capstone Design Course Combining Architectural and Engineering Aspects of Building Design

Abolhassan Astaneh-Asl, University of California, Berkeley; R. Gary Black, University of California, Berkeley

Abstract

A new capstone design course entitled Innovative Sustainable Residential Design was developed by the authors and was team taught at the University of California, Berkeley, for the first time during the spring 2016 semester. The format and manner in which the course was taught introduced innovative pedagogy and technology. The course syllabus presented balanced coverage of structural engineering, architectural design, zero-net-energy, sustainable design, and ethical issues in design. Two faculty members taught the course, one from the Department of Architecture and one from the Department of Civil and Environmental Engineering. The course was taught in one of the design studios in the Jacobs Institute for Design Innovation—a modern facility similar to a modern architectural/engineering (A/E) design office—that houses laser cutters, CNC routers, and a variety of low- and high-end 3D printers. The course had no exams or traditional homework, but coursework comprising research papers, design assignments, an ethics paper, progress reports on student term design project, and a final design report. Students from both architecture and engineering were encouraged to enroll. Leading experts in architecture, structural engineering, zero-net-energy design, and sustainability gave invited lectures, followed by discussion sessions. Students were organized into teams to collaborate on their term project.

This course introduced three important innovations to the classroom. The student design teams devised architectural and engineering computer models, and created 3D rapid prototypes of their structural designs. Professors from two different disciplines taught the course and engaged the entire faculty of both colleges by including guest speakers, reviewers, and critics. And, the co-professors ran the course more like a design studio, with direct and individual contact with the students, and acted more like coaches than the traditional "sage on the stage" teachers.

Introduction

One may ask why so many of the great buildings from antiquity, in virtually every culture, appear as a holistic form, where the structure and the architecture are both innovative and integrated. Is it because the designers and builders actively strove to integrate their two disciplines, or is it because they had not yet been separated? Pondering this question, the authors embarked on an experiment in education. The idea was to take junior and senior students from the Department of Architecture and the Department of Civil and Environmental Engineering and place them in teams tasked with designing an innovative, integrated, and net-zero-energy building for the 21st century.

The course would be co-taught by one professor from architecture and one from civil/structural engineering, and all discussions and work sessions would occur in a studio environment with adjacent maker spaces that supported 3D printing, CNC routers, and laser cutters. The studio was housed at the newly opened Jacobs Institute for Design Innovation at UC Berkeley. Dr. Paul Jacobs was the major supporter of this initiative and, when announcing the establishment of the Jacobs Institute, he stated that, "Today, it is not enough to provide our future engineering leaders with technical skills. They must also learn to work in interdisciplinary teams, how to iterate designs rapidly, how to manufacture sustainably, how to combine art and engineering, and how to address global markets…to create our future." This course was developed to realize this vision. More information on the Jacobs Institute can be found at http://jacobsinstitute.berkeley.edu.

The premise of this course was the concept that a better building would result if the architecture and the engineering were considered together from the beginning of the design process. Herein, better is defined as a cohesive design that incorporates state-of-the-art sustainable practices, engineering principles, and community involvement. This approach is significantly different from current practice, where an architect is tasked with generating a design, and an engineer is then expected to apply mathematics to make it stand up. By the time the engineer becomes involved, many design decisions have already been made, and the architect is committed to those decisions. As a result, the current model lends itself to confrontation, because any design modifications proposed by the engineer, though helpful, are seen as an infraction of the original architectural design.

The proposed model considers the design from the perspective of a master builder, where architecture, structure, construction, and the modern necessities of being energy efficient, are equal components of a design process. In this scenario, the structural system is considered at the very beginning, along with architectural sketches. At the same time that physical models are being contemplated, structural computer models are being generated. This allows both disciplines to influence the design. A modification in the structure that improves its performance can then be examined in a physical or sketch-up model to understand the impact on the architecture and vice-versa. A modification in the architectural model can be considered in the structural model to understand the impact on the structure. The goal of these iterations is to arrive at a synergy between the architectural design and structural integrity. While this integration was the primary goal of this current project, other objectives included emphasizing a zero-energy design, sustainability, best construction practices, and professional ethics.

The course was first offered in the spring of 2016 as a 3-unit elective course in civil engineering and as a 3-unit elective course in architecture. In the next offering, the course will be a capstone design course. The architecture students wishing to take the course enrolled in Arch-159. Similarly, engineering students wishing to take the course enrolled in CE 190, which was a new course created by Dr. Astaneh-Asl. The goal of this course was to engage students in not only structural design but to enable structural engineering students in civil engineering to work intimately as members of an architectural and engineering (A/E) design team, simulating real-world conditions many of them will work in upon graduation. The course will become a capstone design course, as defined by ABET (the Accreditation Board for Engineering and Technology.) The long-range goal is to have the course listed as an elective course in the Department of Architecture and as a capstone design course in the Department of Civil and Environmental Engineering. During its first offering, the course attracted six architecture students and 20 engineering students—15 were majoring in structural engineering, four in environmental engineering, and one in mechanical engineering.

Course Syllabus and Who Should Be Enrolled in This Course?

The course is a 3-unit course that meets for 75 minutes, three times a week, for a total of 4.5 hours of student contact time per week. Two meetings are called lectures with the third one designated as the laboratory section. Although designated as lectures, there are no formal lectures in this design course. During "lecture" hours, both professors and the graduate student instructor (GSI) work in the studio with student teams and discuss various aspects of the design. The third 75-minute session, the "laboratory," was designed for student teams to work with the GSI on their project.

For this first-time offering, the course was open to juniors, seniors, and graduate students. Most students in class were juniors or seniors, with two graduate students from the Department of Architecture. Based on the experience gained this semester, the course should be limited to seniors only. The interaction of graduate students with the undergraduate student members of the design team was problematic. Regarding civil engineering students, only seniors should be allowed to enroll. This was because the skillset required that engineering students be exposed to engineering design courses. Juniors were unfamiliar with higher-level analyses, which included finite-element modeling using computer software programs such as SAP.

The students at the end of the semester were required to prepare a final report and make a team presentation of their work to the class before a panel composed of the two professors and an expert on net-zero-energy design and sustainability. The final report included an explanation of architectural design decisions, structural engineering methodology, sustainability, and zero-energy aspects, as well as construction details and how the design would interact with the community.

Formation of the Design Teams

Teaming is "the engine of organizational learning," [1] and design, as taught in this class, is fundamentally a learning process [2]. Thus, one of the keys to the success of the course is how to organize the project teams. The students were not assigned to individual teams until the third week of class; this gave the students time to get to know one another, allowing them to form teams more naturally. Another key factor is requiring disciplinary diversity on the teams, which, in this case, meant that each team had to contain at least one student from the Department of Architecture and one student from the Department of Civil and Environmental Engineering, who was majoring in structural engineering. This dictated that the maximum number of teams possible was six, which was limited by the number of enrolled students from architecture.

On the day the teams formed, it was announced that it was mandatory that each team contain one architecture student and at least one structural engineering student, with a maximum of 4-5 students per team. The process of devising the teams began by positioning one architecture student at each of six tables, and then allowing the remaining students to sort themselves into table groups; this took roughly 30 minutes. The authors believe that this simple approach to team building, with disciplinary diversity critical to project completion, was so crucial to the success of the course that the authors felt it necessary to highlight this process in this paper.

Team projects are often challenging for students and faculty alike. The many potential pitfalls include students not getting along; students taking advantage of the team grading scheme and allowing their teammates to do most of the work; teams struggling to create a shared goal for their work; and miscommunication. Teams working on complex design projects—such as the one compiled in this class—required an appropriate degree of psychological safety [1] to feel comfortable in sharing ideas, giving and receiving meaningful feedback, criticizing the status quo, and making mistakes. The authors were concerned about these problems, especially in a multi-disciplinary design course, where conflicts over design priorities, opinions, and aesthetics are bound to occur.

In general, the authors, in teaching this course, found that the teams got along well, worked well together, and most members pulled their weight. There were weekly desk critiques focusing on both structural and architectural issues; in the later weeks, these critiques included sustainability and construction practices. From these critiques and face-to-face work with each student, it was possible for the instructors (i.e., the authors) to assess each team's workflow. Throughout the semester, the workflow appeared exceptional and work-distribution equal. The instructors did not observe disharmony in any of the teams.

During the weekly critiques, the authors saw cooperation at a level they had not experienced in other team-based courses. One of the reasons for this may be the result of implicit norms of hearing from everyone. In the case of disagreement, "the expert" could be consulted. For example, whenever a structural engineering question arose, all students provided welcomed input, but they allowed the structural engineering students to have the final say. Likewise, whenever an architectural issue came up. All students verbalized their opinions, but they tended to respect the architecture student in the group and, in the end, deferred to that student's judgment.

Although the distribution of the workload seemed equitable at the beginning of the semester, toward the end of the semester, the authors were approached by two students from one of the teams, who complained that their other team members were not contributing an equal share of the workload required to prepare the final presentation. As a result, the authors sought help from the co-founders of the UC Berkeley Teaming with Diversity program, Sara L. Beckman and Barbara Waugh, who have integrated teaming content into a broad range of project-based courses across the Berkeley campus. The modular content of their program allowed the teams to use an online survey that collects anonymous peer evaluations from the students about their own and their teammates' contributions to the team. The complete program includes approaches for forming diverse teams, materials to launch teams, mid-term check in evaluations and tools for debriefing them, and end-of-semester assessments. In this class, only the end-of-semester evaluations were used. Students were asked to provide a sentence each about the contributions they and their teammates made to their project, and then allocate 100 points, divided among themselves and their teammates, to represent relative contribution. Students received data in return that showed how they perceived their contribution and how their teammates viewed that contribution. This allowed the faculty to receive data that provided them with the bigger picture for each team, which is often better than engaging in "he said—she said" discussions with the students.

The survey's results showed that there were underperforming students on two of the six design teams; one team had two underperformers by the team's reckoning. This was in sharp contrast to the levels of team cooperation and workflow that the authors observed throughout the semester. The survey data, however, provided useful comments, such as "did not produce quality work" or "attempted energy analysis but was not accurate." It is possible that a) such difficulties did not surface in the in-class discussions, or b) these problems occurred in the final two weeks of the class, when students were preparing the final presentation for this class along with work for other courses.

Regardless of the reason, the authors wonder if this breakdown in teamwork could have been avoided if there had been more emphasis on team dynamics throughout the semester. Including a "collaborative plan" for outlining goals, roles, processes, and relationships might have helped students get on and stay on the same page throughout the semester. Using earlier and more frequent peer-feedback mechanisms, such as surveys or "stop-keep-start" team assessments, might have highlighted concerns so that they could be dealt with sooner. Thus, the authors aim in future offerings of the course is to embed more of the Teaming with Diversity curriculum to support the students through their intricate design work.

The Team Design Project

Successful completion of the team design project required a team of four or five students, as the workload would be too much for a 3-unit course with smaller teams. The semester-long project—which culminated in a final presentation before a panel made up of the two faculty members, and a zero-energy design expert (Dr. Ann Edminster), and the rest of the class—required each team to design and engineer a two- or three-story, net-zero-energy housing unit, with between four and eight individual units. All design teams worked on the same site, which was located in a residential area of Berkeley zoned for multifamily housing. The lot was vacant but was being used as a community garden. Each team had to design a residential complex that could accommodate four to eight condominium units. One team elected to design a youth hostel with a community kitchen and separate and communal living accommodations. The authors approved this change in scope. The other teams stayed true to the original architecture assignment.

The structural system for the architecturally designed building included designing the superstructure and the foundations. Each team had to consider construction systems in the overall design to achieve net-zero energy. Most teams chose steel moment frames; these are steel-braced frames and wood framing with shear walls as their primary structural/construction system. To achieve net-zero energy, students considered orientation, shading devices, lighting systems, and enough usable roof area for solar thermal panels and photovoltaic panels. Each team also examined the interface with the community, addressed construction issues, sustainability, zero-energy considerations, and the interaction of the designed building with the surrounding community.

Course Content

While the course was interdisciplinary, and intentionally blurred the traditional lines between those disciplines, there were nevertheless two broad headings of the course—architecture and structural engineering. Under each heading were sub-headings. Under architecture, the authors, as instructors of the course, included "interface with the community" (which had an ethical component to it) and "sustainability," which focused on the use of materials and designs necessary to achieve net-zero energy for the project. Under structural engineering, the authors included "foundation design" and "construction methods and materials," which also contained a sustainability component.

The Architectural Design

The most daunting part of this activity was how to introduce engineering students to architecture and architectural design in a limited time frame and in a way that would enable them to engage in the process so that they would be able to make valuable contributions to the architectural design. In week two, instructors of the course introduced the students to a pattern language (APL) [3]. After selecting 17 patterns that would be most relevant for their project, they were asked to develop a project pattern language to help direct their design. Preparation of the project pattern language was assigned as an individual task, one of the research papers that the students completed during the term.

For this assignment, they were required to read each preselected pattern and re-write it in shorthand, pulling out the essential points. They were also required to choose a new photograph that they felt was archetypical of each of the patterns. They were also asked to pick a few new patterns that they thought might have applicability to their project and complete the same tasks described above.

This assignment had a powerful impact on the project. Because the original APL was written from a humanistic point of view, where the main point of architecture is to respond to the physical and emotional needs of the inhabitants, it was relatively easy for students not having been trained in architecture to connect on an intuitive level. Once they read each of the selected patterns, the engineering students could easily put themselves into the described situation and understand and react to it without needing years of exposure to architectural theory or even architectural history. As an example, take pattern number 112, Entrance Transition, done by a student team in the course. Figures 1(a) and 1(b) show how the pattern begins with a problem statement [3]: Buildings, and especially houses, with a graceful transition between the street and the inside are more tranquil than those that open directly off the street.

Figures 2 and 3 show how the pattern continues with an argument giving positive and negative examples: The experience of entering a building influences the way one feels inside the building. If the transition is too abrupt, there is no feeling of arrival, and the inside of the building fails to be a sanctum. The following argument may help to explain it. While people are on the street, they adopt a style of "street behavior." When they come into a house, they naturally want to get rid of this street behavior and settle down completely into the most intimate spirit appropriate to a house.

However, it seems likely that they cannot do this unless there is a transition from one to the other which helps them to lose the street behavior. The transition must, in effect, destroy the momentum of the tension and "distance" which are appropriate to street behavior, before people can relax completely [3].

(a) A Graceful Transition between the Street and the Inside
Copyright: CO Leong/ Image(s), used under license from Shutterstock.com

(b) An Abrupt Entrance – No Transition
Copyright: Savo Ilic/ Image(s), used under license from Shutterstock.com

Figure 1. Two Different Transitions between the Street and the Inside

Figure 2. Example of a Transition with a Different Combination of Elements: A Common Path Provides an Entrance Transition to a Group of Building Entrances
Copyright: Sean HYPERLINK http://www.shutterstock.com/gallery-578401p1.htm Pavone/Image (s), used under license from Shutterstock.com

(a) Entrance Transition along a Path and through a Wooden Gate
Copyright Andrey B. HYPERLINK http://www.shutterstock.com/gallery-3827954p1.htm Kostin/ Image(s), used under license from Shutterstock.com

(b) Entrance Transition over a Foot Bridge Winding through a Garden
Copyright: Dzianis Ziamskou/ Image(s), used under license from Shutterstock.com

(c) Entrance Transition through an Arch into a Courtyard
Copyright: Marco HYPERLINK http://www.shutterstock.com/gallery-2302076p1.htm Ossino/ Image(s), used under license from Shutterstock.com

Figure 3. Three Additional Examples of Transitions with Different Combinations of Elements

Figure 4 shows how the pattern ends with a solution statement and a graphic representation of the essential points: Make a transition space between the street and the front door. Bring the path which connects street and entrance through this transition space, and mark it with a change of light, a change of sound, a change of direction, a change of surface, a change of level, perhaps by gateways which make a change of enclosure, and above all with a change of view [3].

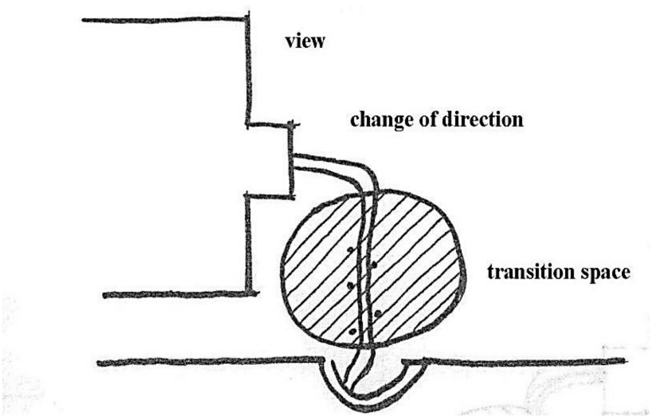
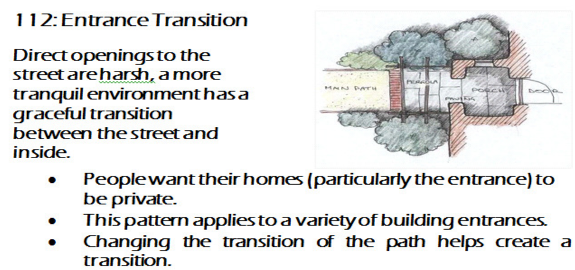


Figure 4. Sketch of Solution

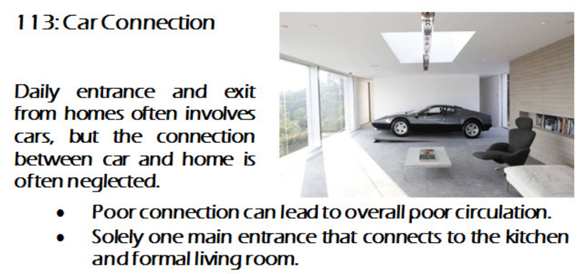
It is easy to see how an engineering student, or anyone else for that matter, could understand all aspects of the pattern, because they can "feel it" and determine for themselves if it makes sense. Once the mental connection is made, they are given a solution statement, some examples, and a graphic to help them engage in useful dialogue about this particular design element in their project. Considering the rather extensive list of patterns required for study, it is no accident that the engineering students became major contributors to the architectural design process. In one of the teams, the architectural student specialized in building science, not design. For this team, the architecture was devised by the team without a team architect. Moreover, for all teams, heated discussions occurred among the students during their design sessions. Figure 5 shows student work on the APL assignment.

This assignment also had the effect of putting team members on more of an equal footing with the architecture student. While most team members tended to defer to the architecture student for much of the graphical portion of the design, such as sketch-up models, plans, and sections, other students were still active participants, and the final architectural result was most definitely a joint team effort. The final report contained: 1) a section on the architectural process, which included an explanation of the architectural design decisions that had been made; 2) the architectural plans, including a site plan, sections, and elevations; and, 3) a 3D computer model along with a 3D rapid prototype physical model. One camera shot of the computer model was selected for rendering. Figure 6 shows architectural renderings of the six team designs.

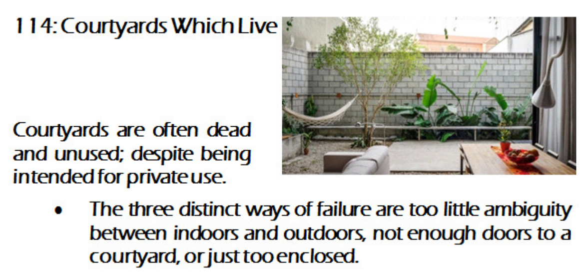
(a) Garden Placed in a Half-Hidden, Side-by-Side Position



(b) A Transition Created between the Street and the Front Door



(c) A Transition Created between the Car and the House



(d) The Courtyard Made Central

Figure 5. One Student Team's Work [4] on the Pattern Language Assignment

Figure 6. Architectural Renderings of the Six Team Designs

Interface with the Community

Each team worked on the same site, which was located in a residential area of Berkeley, California, about two miles from the campus. It was a vacant lot with a tall, 1.5-story youth center on the south side and a tall, single-story storage building on the north. The lot fronts on a residential (Bonar) Street to the west and a community park to the east. At the time the project was assigned, the site was fenced off on the east and west, and was planted in vegetables, which were part of a community outreach program with the youth center. Only community members associated with the garden could enter the site.

Some students expressed initial concern with the site chosen, given that they would be placing their building onto a community garden. This caused an ethical dilemma among the teams. Most teams dealt with this aspect of the project by making design decisions that endeavored to interface with the community. One team created a series of gardens on the ground floor, and made the site permeable from Bonar Street through to the community park, thereby allowing the community to use their site for access to the park. This resulted in potential security issues for the new residents that the team had to address. Another team built their condominiums as platforms in a structural steel tree, keeping the original ground plane free and clear of a building footprint in order to tread as lightly as possible on what they considered hallowed ground. By placing all of their units up in the air and parking underground, they were able to keep most of the original site accessible to the community for use as a garden. Some square footage was required for the base of the "trunk" and a path that led to the base of the trunk; the design called for private stairs and an elevator, which allowed the community onto the property but addressed issues of privacy and security for the residents.

Energy and Sustainability Issues

The only required textbook for the course was *Energy Free-Homes for Small Planet*, by Ann V. Edminster [5]. Each team was required to prepare an annual kWh (kilowatt -hour) demand report, using published data for space heating and cooling in the applicable climate zone and published data from manufacturers of appliances with estimated usages for a typical American family. From this research, the teams estimated the size of a photovoltaic array (PV) and solar water heater to assist in determining locations and areas required to accommodate the hardware. In addition to the team design project as outlined above, each student was responsible for completing three research papers—one that addressed architecture, one that addressed structural/ construction systems, and one that addressed professional ethics.

This part of the project required teams to think about the materials selected for construction: where they were sourced, how renewable they were, how much carbon gas their manufacture generated, and their durability. As part of the requirement that the buildings had to be net-zero energy—meaning that they had to generate all of the power on site—students had to consider materials and designs that provided insulation, prevented or reduced thermal bridging, reduced solar insolation, and generated electricity and heated water. A wide variety of designs and techniques were explored. These included green roofs over living spaces, used as a private outdoor space for the units above, special glazing that reduced heat gain and generated electricity, solar hot-water heaters and ground-source heat pumps, brie solei's (which provided sun shading and generated electricity), and a glass wall designed so that water could run through it, thus cooling it down at night through emissive cooling and collecting heat during the day, to name a few.

Students were specifically encouraged to propose and design innovative solutions that are still in their infancy and years away from implementation. Students were required to calculate their annual demand load from space conditioning, appliances, and hot-water generation, and then calculate the amount of area needed to provide room for power-generating apparatuses such as PV panels and solar hot-water panels. One of the team members either volunteered or was assigned (by the other team members) to become the "expert" and direct this part of the design work.

Structural Design

Each team had to design the structural system to resist gravity and lateral loads, meaning that the team had to design a complete building structure and prepare a finite element model of their design. In building the structural model, the students used the SAP2000 structural analysis software [6]. Based on the results of the finite element analysis, the students were required to perform stress checks on their structural members and size them. As stated earlier, students performed several finite element analysis iterations to bring the structure and the architecture into alignment. As part of the final presentation, each team was asked to prepare a framing plan and details of the main structural connections. They also had to design the connection to the ground and design a foundation. Figure 7 shows the structural finite element analysis models for all six team designs.

Because this course was being offered for the first time, the authors were concerned that requiring the undergraduate student teams to perform a seismic design would impose a significant amount of structural engineering work beyond what a 3-unit course should require. The instructors were also concerned that some students might not have been exposed to the concepts of seismic design and earthquake loading in other courses, thus requiring a significant amount of lecturing to provide the necessary background. However, the authors announced that if any team wanted to perform a seismic design of their buildings, the authors would assist them so that they could present the results in their final report. Two teams had members who were very familiar with the finite element analysis and design software SAP2000 [6], and so chose to perform a seismic design for their structure.

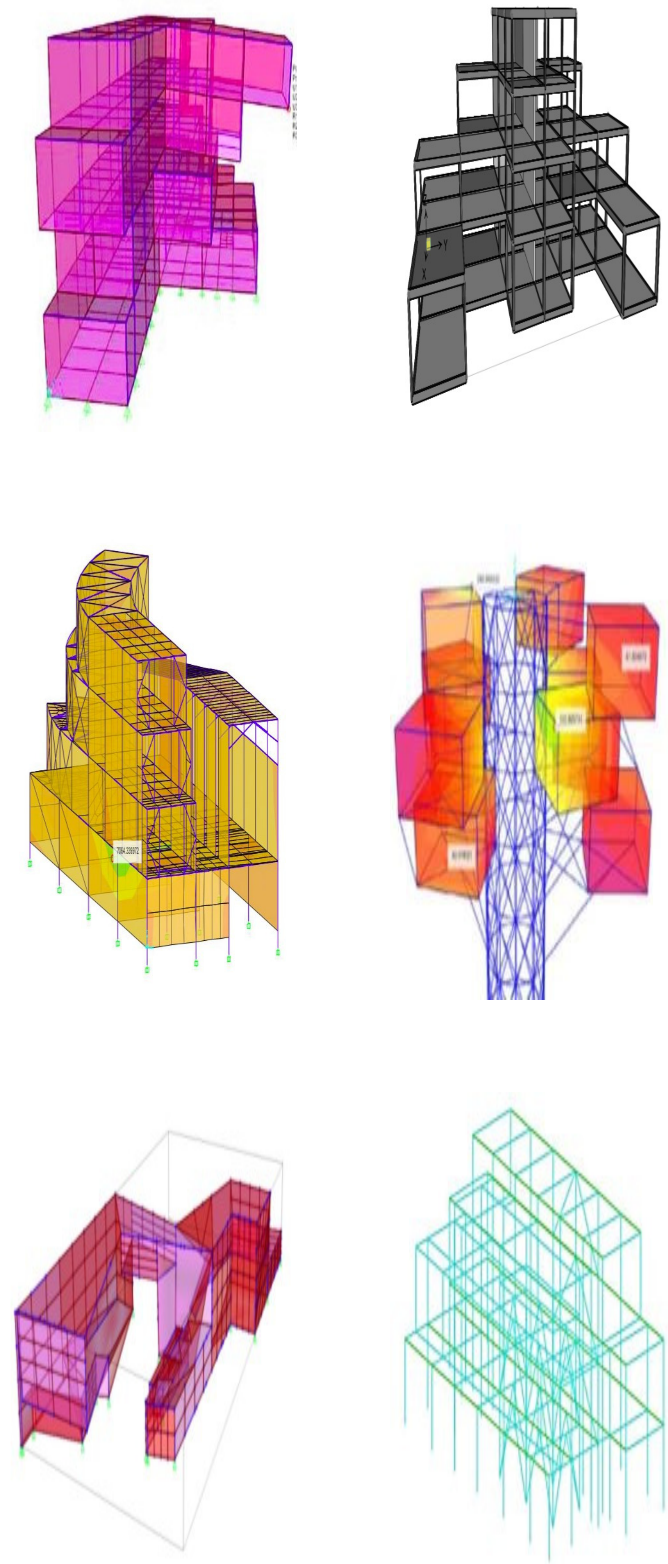
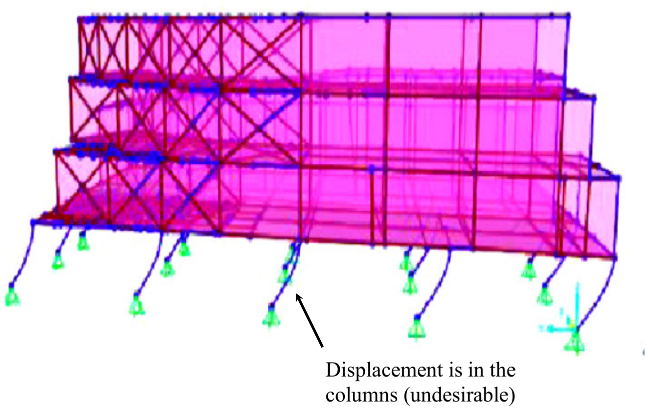
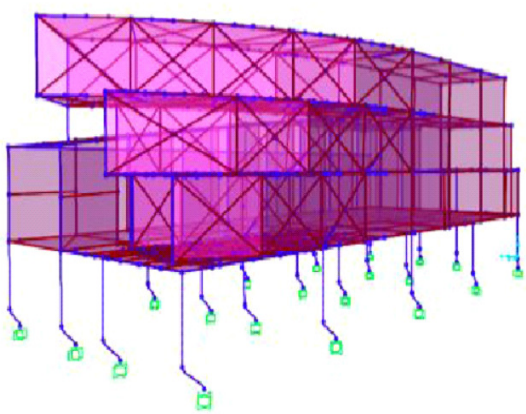


Figure 7. Finite Element Models of the Six Team Designs

The other four design teams that did not conduct a full-fledged seismic design were required to develop a lateral load-resisting system in their structural model to resist the wind and lateral seismic loads. Of the two teams that did perform a seismic design, one chose base isolation using friction pendulum bearings [7], which was an appropriate choice, given that their very rigid framing system was made of vertical and horizontal trusses and X-bracing and had very high stiffness. The other team chose to use a traditional lateral force-resisting system, since their framing system was a relatively flexible moment-frame system not suitable for base isolation. Figure 8 shows the finite element analysis model for the structure of the design team that used base isolation in their seismic design.



(a) Seismic Analysis Model of the Structure without Base Isolation Showing Large Lateral Displacement. The Structure Also Has Large Seismic Forces



(b) Seismic Analysis Model of the Structure with Base Isolation Showing Reduced Lateral Displacement

Figure 8. One Team's Analysis Model with and without Base Isolation [4]

Foundation Issues

Although the design challenge specified that the building is located in the flat lands of the city of Berkeley, no specific soil conditions were given. The teams could decide what type of soil conditions might exist under their designed building and, thus, were tasked with designing a proper foundation system for that soil condition and applied loads. The teams considered the soil to be dense soil or soft soil. Depending on the assumption made, the foundations selected were spread footing or mat foundation or, in one case, pile foundations.

Construction Issues

Each team was required to propose a construction scheme and construction materials, and then draw a typical wall section showing the connection of the foundation to any intervening floors and the roof. The teams were also expected to study the construction sequences and make recommendations on how their designed building would be constructed.

The material used in construction could be traditional wood, steel, concrete, a combination of these materials or other historical material (such as brick or adobe), as well as modern and innovative construction materials such as straw-bale construction or fiber-reinforced polymer composites. One of the tasks early on in the semester was for students to research and collect publications on the various materials used in the construction of homes throughout history, starting with cave dwellings, adobe homes, and then moving into more modern materials such as steel, aluminum, reinforced concrete, and fiber-reinforced polymers. Students using the collected information had to write a research paper on the advantages and disadvantages of each of the construction materials. The purpose of this assignment was to have students research and collect information on various building construction materials and discuss the pros and cons of each material in terms of mechanical properties, cost, sustainability, durability, and eventual demolition and recycling.

Conclusions

This new course provides architecture and engineering students the experience of working together in a collaborative environment; an environment in which both disciplines are valued and appreciated for the assets each discipline brings to the design table. By having architecture students work closely with engineers, they learned some of the tasks that engineers perform in the pursuit of the structural design, and gain a much greater understanding and appreciation for engineering methodology. Conversely, by requiring engineering students to participate in the creative side of design, they can acquire an appreciation for design concepts that go far beyond the mechanics of structural integrity. It is the hope and belief of the authors, who developed the course and taught it for the first time, that this exposure will lead to a more holistic working environment for both professions, ultimately resulting in a built environment that is more economical, energy efficient, sustainable, and healthy.

Although the course could theoretically be taught by a single faculty member, for example an architecture professor with knowledge of engineering design or a structural engineering faculty member with knowledge of architectural design, it is the authors' recommendation that the course be co-taught, with one professor from architecture and one professor from structural engineering. Having co-instructors from the different disciplines provides students with firsthand knowledge of the relationship and conflicts inherent between the two disciplines. The pattern language book and the ethics paper are indispensable for two reasons: they provide a crash course in architectural theory so that engineering students can engage from the beginning in the preliminary architectural design, and they introduce students to professional ethics that emphasizes the importance of ethical conduct in design.

The selection of special topics and the speakers chosen to speak on these topics is an important part of the course that the authors feel was not perfectly orchestrated in this first offering. The invited speakers were from architecture, zero-energy design, structural engineering, and engineering ethics fields. The authors plan to give this more careful thought in future course offerings and invite experts from construction and sustainability fields as well. Finally, critical assessment of the internal team dynamics should occur early on and throughout the entire semester to ensure that each member of the student design teams is pulling his/her fair share of the workload and to emphasize that teamwork is greater than the sum of the team members' work.

Acknowledgments

On the final day of class, and one week before the final project presentation was due, instructors of the course asked the students to share their experiences and make recommendations about what they would change in a future offering of the course. Their comments were thoughtful, sincere, and extremely helpful. As the authors move into a second offering of the course next year, these observations will be referred to again and again. This invaluable input is sincerely appreciated. Professors Barbara Waugh and Sara Beckman of UC Berkeley were invaluable in helping assist students in improving their teamwork skills and conduct a survey at the end of the semester to assess student collaboration and participation. Their work was very helpful, and the authors sincerely appreciate their time, and the valuable results gleaned from their teamwork survey. The authors would also like to express their sincere appreciation to Claire Johnson for her excellent editing of this manuscript.

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LEAN AGILITY AT SCALE: A ROLE FOR STRATEGY IN DETERMINING PERFORMANCE

Andrew J. Czuchry, Sr., East Tennessee State University; Andrew J. Czuchry, Jr., ADP

Abstract

Executive leaders direct their organization with a strategic orientation from the top down. In a classic closed-system approach, the strategic plan feeds into the initial execution plan but no feedback is subsequently provided once execution of the plan begins. This approach is sufficient when the market is highly constrained and/or changes to process execution are expensive. The organization deals with innovation as a closed-system research and development project, and a traditional approach in project management provides a viable execution model. What happens when the constraints do not apply, such as when a market varies and system requirements need to be accommodated even after process execution begins? An open-system is required to engage the client in the execution process. This is when agile project management flourishes; yet, from a CEO's perspective, this appears as organized chaos and the challenge becomes how to measure performance. To that end, the purpose of this study was to determine eight guiding principles for measuring performance in an open-system environment.

Introduction

Achieving lean agility at scale can be viewed as a nonlinear systems engineering challenge to an organization's sustainability in today's competitive business arena. The National Baldrige Criteria provide a proven systems framework to improving performance and enhancing competitiveness [1]. The aims of the applied research reported in this paper are: 1) to suggest a systems framework for addressing both closed and open approaches to innovation, by leveraging a proven strategic planning process and simultaneously embodying dynamic program management practices; 2) to provide coaching points and implementation principles for executing such a framework to mitigate risks when lean agility is applied at scale in a large service sector organization; 3) to illustrate the framework and provide success metrics and measured improvements when applied to a large Fortune 500 organization with an innovative information technology growth strategy; and, 4) to recommend a research path forward.

The first author's experience serving as an examiner and member of the Tennessee Center for Performance Excellence (TNCPE) Panel of Judges for 20 years, and his dozen years at Raytheon as a senior executive, coupled with the second author's experience as a member of the automatic data processing (ADP) leadership team, provides a unique set of talents and an ideal study setting. ADP, LLC is a Fortune 500 company providing global business processing and cloud-based solutions. ADP builds configurable human capital management solutions that are designed to meet client goals of providing improved compliance, reducing costs, and affording a more human resource for employees; as an added dimension relevant for the applied research discussed here, business agility and innovation in information technology are strategic pillars across the global enterprise of ADP.

The TNCPE is a Baldrige-based state quality award program with four levels of recognition. Over the twenty-year window cited above, more than 1000 Tennessee organizations were reviewed. By national policy, organizations must win their state's highest level of recognition first, before competing for the National Baldrige Award. During this window, Eastman Chemical, Federal Express, Caterpillar Financial, and Pal's Sudden Service received Tennessee's highest award level, and subsequently won the National Baldrige Recognition. One important point is that although recognition is nice, organizations generally pursue the process to improve their performance and develop the leadership talent within their organizations. The authors' joy has been observing the growth in the leadership talent that results from the TNCPE process. Benchmarking both metrics and processes for achieving outstanding results is fundamental. Excellence-level criteria mandate that a two-step strategic planning process must have both strategy development and deployment phases. Furthermore, action plans must demonstrate superior results that are directly linked to these processes [1].

Exhibit 1 has been compiled from these best practices and augmented with the authors' practical implementation experiences. Quoting NASA's Joe Shea in the late 1970s, "One thing that I learned while serving on the President's Commission addressing cost overruns is that if you want to control something you must be able to measure it!" Although not national Balridge winners, ADP and Raytheon have deployed management approaches to ensure strategic alignment and measurable accomplishments tied to specific goals and objectives. At the 2016 TNCPE Quality Conference, the authors were pleased that the Excellence Award winner advocated a similar approach to deploying strategic action plans. The authors draw on the strategic planning process best practices summarized in Exhibit 1, coupled with practical project management experience, to suggest the conceptual implementation framework in Figure 1.

Exhibit 1. What Excellent Organizations Use as a Strategic Planning Process

Strategy Development
- Review mission, vision, values, core competencies, strategic advantages, and strategic challenges.
- Assess Research & Development and innovation results.
- Analyze financial performance, investment returns and strategic partnerships and alliances.
- Study global competitive landscape, market growth opportunities, legal and regulatory constraints.
- Conduct a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis on a business unit by business unit basis.
  - □ An organizational feedback process consisting of cascading down and percolating up SWOT goals is often most effective.
  - □ Strengths and Weaknesses are an internal focus while Opportunities and Threats are external.
- Address past performance in the context of market growth potential and share.
- Benchmark competitors and review sustainability, innovation and financial outlooks for your entire organization compared with benchmarked best practices and associated metrics.
- Develop key success factors for each business unit. Then examine the entire organization from a total systems perspective. Focus on innovative technology and business models simultaneously.
- Develop Goals, Objectives and measurable performance targets.
- Check alignment with key success factors. In this context key success factors should be limited to the overarching aims for the entire organization.

Strategy Deployment
- Develop strategies for each business unit ensuring alignment with overarching key success factors.
- Each business unit develops detailed operational plans.
  - □ Often growth strategies merit a detailed business plan.
  - □ Risks of independent technology centric and business centric should be formally assessed and reviewed at the Senior Management Level.
- Once approved operational plans are implemented and reviewed.
- A closed loop performance assessment and corrective action system such as the Plan-Do-Check-Act Cycle is often important.
- Operational tools such as lean thinking and Six Sigma are often part of the strategy deployment process.
  - □ Such projects are generally reviewed quarterly at the business unit level and annually at the organization level.
  - □ Improvement opportunities and lessons learned are then provided as inputs to an annual strategic planning session.

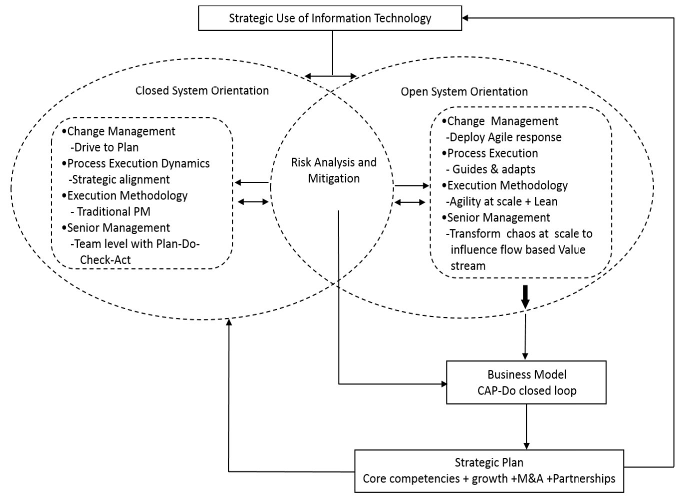

Figure 1. A Conceptual Framework for Implementing Agile Project Management at Scale

Literature Review

Agile software development emphasizes the following foundational values: individual and team interaction, incremental value delivery, client collaboration, and dynamic responsiveness to change [2]. Embedded within the descriptions of these foundational values is a relevant observation that the values do not inherently exclude formulation of any of the following constructs at an enterprise level: defining process models, capturing requisite levels of documentation, performing requirements-centric contract negotiations, and/or executing structured planning cycles.

The judicious application of such enterprise-level constructs is enhanced through the collection of execution principles serving as guiding pillars for delivering results via Agile software development practices [3]. Furthermore, a broad collection of Agile methodologies has been published both as practical models for fulfilling the values and practices via descriptive execution models, and as depictions of an Agile solution space that bridges small and large enterprises. The most commonly practiced of these methodologies include Scrum and XP at the team level [4-10], enterprise-driven "at scale" models for Lean Agility [11-13], the Scaled Agile Framework [14], and RAPD [15]. However, even given the broad solution space covered by these published methodologies, a gap remains relative to bridging the execution dynamics as global enterprises transition their practices across each leadership level and disciplines within a global company. Related analyses are captured for business agility approaches, where information technology is used as a tool for increased agility and competitive advantage [16] and is exacerbated when information technology is part of the product itself.

A useful reference [17] addresses key IT issues and focuses on three areas of recurring importance: concerns of IT executives, investments, and organizational impacts. Overall, the top ten concerns have remained relatively constant since 1980. Among the recurring concerns, IT and business alignment, IT strategic planning, and security and privacy have appeared in the top 10 since 2003. Business productivity and cost reduction, introduced in the Society for Information Management (SIM) survey in 2007, has consistently remained among the top three concerns since 2009. In the 2012 SIM list, business productivity and cost reduction emerged as the #1 concern [17]; the #2 and #3 concerns were IT and business alignment, and business agility and speed to market, respectively. IT strategic planning ranked #6 overall in the 2012 SIM Survey.

Two of the top three concerns in the 2012 SIM list, IT and business alignment, and Business agility and speed to market, were the focus of this current project. Extending this work and incorporating the authors' experience with organizations adopting the National Baldrige Criteria, combined with the fact that 17% of respondents ranked IT strategic planning as their number one concern, the authors suggest that the #6 top concern of the 2012 SIM list (IT strategic planning) be considered as a candidate for future research—refer again to Exhibit 1 for a summary of benchmarking results for strategic planning best practices.

One caveat is important when discussing innovation in business and technology: there is a difference between the use of the terms "open system" and "closed system," when appearing in business literature, as compared to engineering literature. In business literature, a closed system is one that relies on its internal research and development, and tends to pull innovation through the supply chain to deliver to its customers [18]. Examples of closed-system innovation can be seen in the Apple Corporation. Open systems in business literature, on the other hand, tend to engage the customer more directly in the innovation process. Innovations will then be pushed throughout the supply chain. ADP traditionally leverages a model of closed-system innovation. An example of leveraging both closed and open practices is Raytheon. In their second-source programs, Raytheon found product cost-saving innovations lying dormant throughout the supply chain (closed-system approach). Changing the prime contractor supplier relationship to a more open-system approach resulted in simultaneous reliability improvements and cost reductions. As a consequence, a cultural shift combining open-system and closed-system strategies became a strategic competitive advantage, when dealing with complex products involving multiple tiers of suppliers. Similar situations have occurred in the automotive industry.

On the engineering literature side of the equation, closed-loop control systems employing appropriate feedback are more stable than open-loop systems. Closed-loop tracking is now pervasive in quality management systems such as ISO and Baldrige, and has even become a requirement for university accreditations. Closed-loop tracking and corrective action systems, such as Plan-Do-Check-Act (PDCA) Shewhart [19] and Plan-Do-Study-Act (PDSA) Deming [20], have become part of systems engineering, much like Wi-Fi and apple pie. However, when IT agility is included from an engineering perspective, it is critical to clearly distinguish between process and products. This is important because IT can be either a tactical enabler of organizational agility [21] or it can be a product itself combined with business services, as in the project discussed here. The result of applying IT and business agility together, across a combined product and service suite, can be a new weapon for the strategic arsenal, leading to a transformation in a successful organization's business model [22].

In addition to publications on agility execution for both information technology and business teams, another body of knowledge important to the authors' research agenda is the outstanding work published in the Harvard Business Review (HBR) on the difference between the art of leadership and the science of management [23]. As a perspective on delineating the differences between leadership and management, the authors found Bohn's work [24] in chronicling the transition from art to science in manufacturing technology insightful. Analogous transitions from art to science may also apply as information technology agility is extended to encompass business agility for information technology companies. Overall, the intent of this current study was to introduce a framework to help address challenges in business agility execution and adoption, as experienced in large global business enterprises.

An Eight-Principle Methodology for Using the Conceptual Framework for Implementing Agile Project Management at Scale

<u>Principle 1</u>: The strategic plan serves as an overall guide for alignment and establishing touchstones for measuring performance. Starting with the major objectives resulting from the planning step in Exhibit 1, goals with measurable performance are viewed as the scope of work for subprojects in the action planning and deployment phase. As a top-level question, ask how IT will be used in achieving these objectives. Define, at the top level, the scope of IT necessary and establish priorities. Generally, it is best to have each objective defined as subprojects; such an approach helps ensure strategic alignment.

Principle 2: These touchstones are separated into defined elements with binary completion. Avoid percent completion, in spite of what some methodologies promote. Define what constitutes acceptable completion for each subproject. Then, as the initial step for market variability, ask how stable the requirements are. Note that this requires marketing input, and having a strategic champion for the overarching objective may help. Generally, this initial step is a project management task that may not be appropriate for functional managers.

Principle 3: Each touchstone is further divided into specific tasks. What are the major tasks? What resources are required to achieve acceptable completion defined in principle 2? Exhibit 2 shows how a plan-of-action (POA) chart format can be helpful in getting individual "buy-in" and "binary milestone" definitions. The POA chart is helpful when dealing with innovation management, because when individuals establish their completion dates they also become accountable.

Exhibit 2. Sample Plan-of-Action Chart

	Tasks	Responsible Individual	Completion Date		
			Plan	Outlook	Actual
1.					
2.					
3.					

Top Priority Effort: Brief Description, Lead's Name, Phone Number and Email Address, Completion Measure

Principle 4: Groups of tasks are defined as a subproject with binary completion measures. For each subproject, ask what the major risks and/or barriers to completion are. Project management, including agile project management constructs, provides a solid approach to risk management. Let the team members responsible for completing the tasks assess the risk's magnitude and probability of occurrence. Do not get seduced by Monte Carlo analyses or other fancy risk-assessment techniques; they are overkill and typically not worth the effort. "Risks" are in the eyes of those responsible for completing the work. When risks are low to moderate, ask what value the subproject adds to the customers, or to the sustainability of the organization. Now get ready for the collision between art and science. Since innovation is, by definition non-linear in general, greater benefits from innovation in the use of technology carry with them higher ambiguity. How will you know that you are making progress?

Principle 5: The subprojects are segmented into planned value from the client's perspective. Ask the following: How confident are you in achieving subproject milestone/touchstone completion? Often, it is helpful to define 90% confidence levels as "betting your paycheck on completing the task by the given date nine out of ten times." The authors look at the subprojects and segment them into planned value from the client's perspective. This is the key transition from the R&D closed-system perspective to the open system with client engagement. However, please do not conclude that an open system with agile PM is always best! What if engaging the client prematurely increases the security risks of losing intellectual property trade secrets or proprietary software? Perhaps the marketing team can provide the appropriate bridge. The authors' experience suggests that the technical support to marketing is what is called for in these situations. A marketing manager, together with a technical support person, often is the best approach to solving a combined business and technology problem. If the appropriate decision is to continue with a closed-system orientation, please refer to Figure 2 for deployment and include strategic alignment through interaction with senior management and provide quantified risk mitigation tasks. Creativity and innovation are encouraged, and marketing inputs are derived and used with a classic team interaction and a Plan-Do-Check-Act closed-loop management system. Large discontinuous innovations addressing overarching strategic objectives, or contributing to market share and growth, can be studied as independent projects. It is generally best to explicitly identify additional scope and propose an internally funded research and development project, or present as a business growth plan or as a defined experiment in order to elicit market feedback to be reviewed with the strategic planning committee. Explicitly addressing additional scope is one alternative for dealing with the chaos and disruptions that are often essential in innovation. On the surface, this apparent advantage of agility may carry a hidden downstream risk of customer disappointment, due to schedule slippage plus cost growth. This can be addressed by explicitly engaging the client throughout the journey, if that is viable from a security perspective. Remember that bad news does not get better with time, so planned feedback increments can be a valuable risk-mitigation tool. Upfront acknowledgement of such innovation risks with alternative paths forward, tied to cost, benefits, and schedule, often helps justify customer engagement.

Principle 6: Determine the applicable degree of client engagement as part of the overall team. The items presented in Principle 5 are key drivers in the transition from the R&D closed-system perspective to the open system with client engagement. When marketing approves a shift in the level of client engagement, the authors identify and prioritize the top 20% of the tasks that will receive 80% of the return incrementally. One approach is to grade Likert items, ranked with 1 being fluid with low stability and 5 being firm and stable. Ideally, each item with a binary touchstone would be ranked in two dimensions: a) value to the customer in terms of importance and b) impact and stability of requirements. High impact with moderate to high stability (3 or higher) would be given higher priority. A Pareto chart, which gives the 80% value for the 20% work necessary, can be combined with root cause-and-effect impacts to differentiate between causes and correlation. Often, using the collective team knowledge together with Google search is adequate for the prioritization process, as long as customer benefits are quantifiable. There is also content and relationship building that emerges from such a process, because customers share in the innovation and the use of information technology in helping customers gain market share. A modified BCG matrix, guided by Walter Synder's unpublished work while on sabbatical with the Oak Ridge National Labs around 2000, is very helpful in assessing the use of information technology on market share.

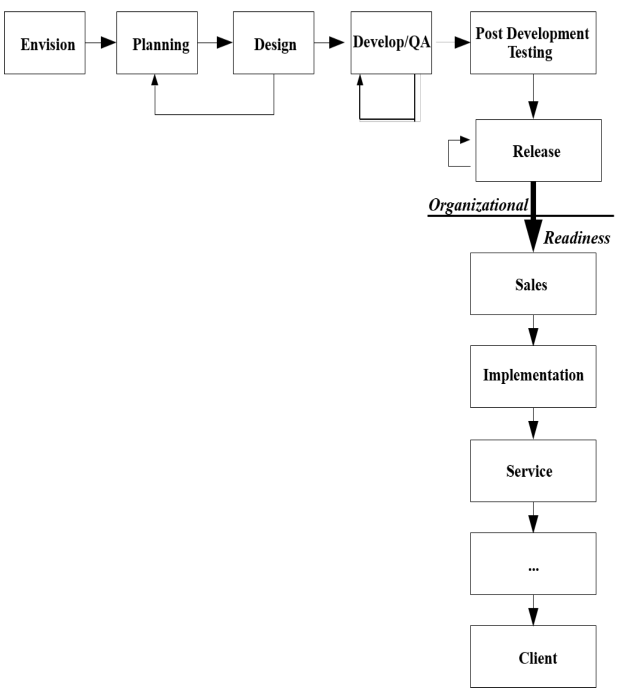

Figure 2. Initial State: Value Stream has Gaps in Feedback (feed-forward execution) and Changing Requirements Becomes Disruptive (closed requirements flow)

Principle 7: Figure 3 shows how to leverage the approach of the solution lifecycle as an overarching guide. Historical data, in terms of market share, become of significant benefit when growing the parent company's market strategic planning process.

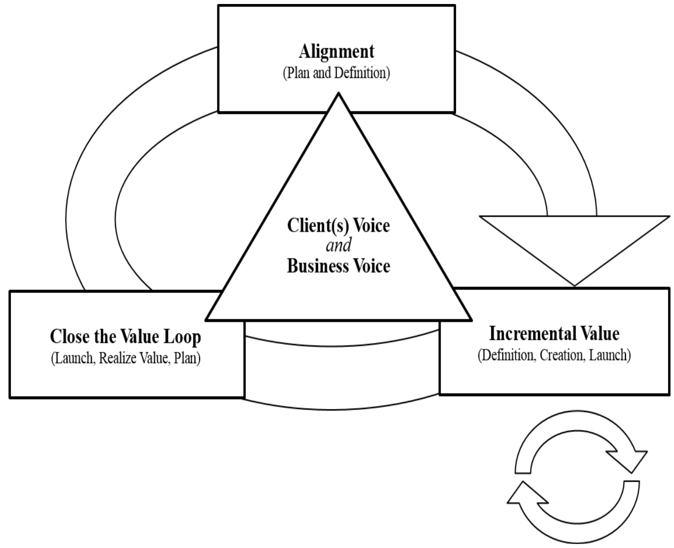

Figure 3. Target State: Full Value Stream Embodies Explicit Feedback (dynamic feedback execution) and Responsive Requirement Adaptations (open requirements input)

Principle 8: Execute with incremental delivery, including feedback to the client and the strategic plan, in order to sustain alignment. Armed with the customer's additional buy-in, transition to the agility framework and execute with incremental delivery and feedback to the client and overall strategic plan to sustain alignment. In this step, the authors were careful to deploy a CAP—Do Improvement, where stepwise changes do not cause huge changes in either organization's business model. Such an approach appears essential in transforming from the chaos when agility is implemented at scale to a more systemic incrementally stable introduction of innovations. Large innovations with impacts on the DNA of engaged organizations can be explored by deploying a Plan-Do-Check-Act Shewhart Cycle [19] with the plan step using a "Just Imagine" approach. Such a more highly non-linear subproject was analyzed in a broader strategic context of growth and innovation acquisition. Mergers, strategic alliances, acquisitions, and R&D decisions were deployed in a more traditional leadership style. In any event, the IT effort capitalizes on the creative dimension of agility, while eliminating waste, due to dynamic instability of requirements in the global marketplace.

Conclusions and Managerial Implications

Four aims were accomplished in this study: 1) to suggest a systems framework for addressing both closed- and open-engagement approaches to innovation, by leveraging a proven strategic planning process and simultaneously embodying dynamic program management practices; 2) to provide coaching points and implementation principles for executing such a systems framework to mitigate risks, when lean agility is applied at scale for software development in a large service sector organization; 3) to illustrate the systems framework and provide success metrics and measured improvements, when applied to a large Fortune 500 organization with an innovative information technology growth strategy in the service sector; and, 4) to recommend a research path forward. These aims deal with nonlinear systems implementation in the business context. The achievement of outcomes at each level was not uniform and certainly discontinuous.

The first aim was accomplished by providing a practical approach to using strategy as a means of measuring performance. Typical metrics were used from generally accepted good practices in software development-driven agility; these included product deployment cycle time, timeline to new revenue, customer satisfaction as measured by Net Promoter Score, growth in revenue, elimination of waste, reduction in planned outages, and reduction in effort for implementation and service. The second aim is depicted in the transformation synopsis of the solution execution model of a Global Fortune 500 company, as shown visually via three figures with eight implementation principles. Figure 1 provides a strategic view of closed and open approaches to innovation, linked by a risk analysis and mitigation approach extracted from the Project Management discipline. Figures 2 and 3 depict the beginning and ending states of the process transformation. The following list provides a summary of the eight implementation principles for execution, and provides the backdrop for addressing the third aim. Because the approach has merit for IT, the authors are optimistic that some benefit may also accrue for innovation management in manufacturing as well; in conjunction with addressing the fourth aim, please see the path forward for future research summarized below.

1. The strategic plan serves as an overall guide for alignment, and establishes incremental touchstones for measuring performance.
2. The touchstones are separated into defined elements with binary completion.
3. Each touchstone is further divided into specific tasks.
4. Groups of tasks are defined as a subproject with binary completion measures.
5. The subprojects are segmented into planned value from the client's perspective. This provides the key transition from a closed-system to an open-system perspective with client engagement.
6. With the client potentially engaged as part of the overall team, identify and prioritize the top 20% of the segments that will receive 80% of the return incrementally.
7. Leverage the solution lifecycle as an overarching guide for execution.
8. Execute with incremental delivery, including feedback to the client and/or the strategic plan to sustain alignment.

With ADP as a mini-case study setting for this study, agile project management at scale was pursued. Figure 2 shows a role-centric, linear handoff, release-centric model across the value stream, which, in the initial state, was a feed-forward execution and closed requirements flow system. Figure 3 shows a value-centric, collaborative, client-centric model across the full value stream, which, in the target state, was a dynamic feedback execution and open requirements input system. Figure 3 shows how the target state, representing enterprise business agility, was achieved through the ADP solution lifecycle. This was an important accomplishment because the market was dynamic and the strategic plan needed to incorporate feedback so that it could adapt to the feedback from the market. Execution was accompanied by a full playbook and corresponding proof points produced as the lifecycle model was ushered through the transformation from problem to solution concept in order to pilot to adoption for operational execution.

Key outcomes relative to established objective baselines within one year specifically shortened product deployment timeline by 18%, reduced Net Promoter Score Detractors by 48%, reduced unplanned outages by 96%, increased revenue, shortened time to new revenue, eliminated waste in misaligned requirements, and reduced the effort to implement and service clients. These results are encouraging and serve as a preliminary indication that the framework indicated by Figures 1-3 with the eight principles for implementation may prove helpful to the service industry. The path forward, with regards to future research, is to conduct qualitative and quantitative studies regarding innovation in the service, production, and education communities. The authors appreciate the comments and suggestions from the peer-review process, and these improvements have been incorporated into this paper.

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Perceptions of the Advanced Manufacturing Competency Model for Curriculum Development

Mark Doggett, Western Kentucky University; Muhammad Jahan, Western Kentucky University

Abstract

The advanced manufacturing competency model (AMCM) emphasizes building competencies at all levels, ranging from the shop floor production worker to manufacturing engineers. It consists of different levels of competencies, organized hierarchically. The levels are personal effectiveness, academic, workplace, industry-wide technical, industry-sector technical, management, and organization-specific competencies. In this study, the authors examined the perceptions of manufacturing students, faculty, and industry advisory board members regarding the AMCM. The authors evaluated the manufacturing program, based on perceptions of the AMCM competencies, and the curricular coverage required for entry-level manufacturing professionals. Specifically, the study addressed these questions:

- What competencies of the AMCM are the most important for entry-level manufacturing professionals?
- What competencies of the AMCM are most frequently covered in the manufacturing program?
- Is the advanced manufacturing competency model compatible with what is being taught in your manufacturing program and the competencies that are important for an entry-level manufacturing professional?

Overall, the AMCM was perceived to be compatible with important competencies for an entry-level manufacturing professional and taught in a manufacturing program. However, for most competencies, respondents perceived the extent of curriculum coverage to be less than the importance of the competency. Areas for consideration included an increased emphasis on professionalism, responsible behaviors, thinking skills, reading, oral, and written communication. In addition, respondents indicated that the program should consider increased attention to the competencies of planning, organizational skills, adaptability, and practices for a safe work environment.

Introduction

Developed and released in 2006 by the U.S. Department of Labor's (DOL) Employment and Training Administration, the advanced manufacturing competency model (AMCM) provided a skillset framework for manufacturing jobs [1]. Since its release, the model has been considered a resource and guideline for manufacturing industries and educational institutes across the country. In 2010, the DOL collaborated with The National Association of Manufacturers (NAM), the National Council for Advanced Manufacturing, and the Society for Manufacturing Engineers (SME) to update the model with current practice. The model emphasized competencies at levels ranging from the shop floor production worker to manufacturing engineers. The AMCM includes seven different levels of competencies, organized hierarchically. The levels are personal effectiveness, academic, workplace, industry-wide technical, industry-sector technical, management and organization-specific competencies. Figure 1 shows the updated AMCM, released by the DOL in 2010 [2].

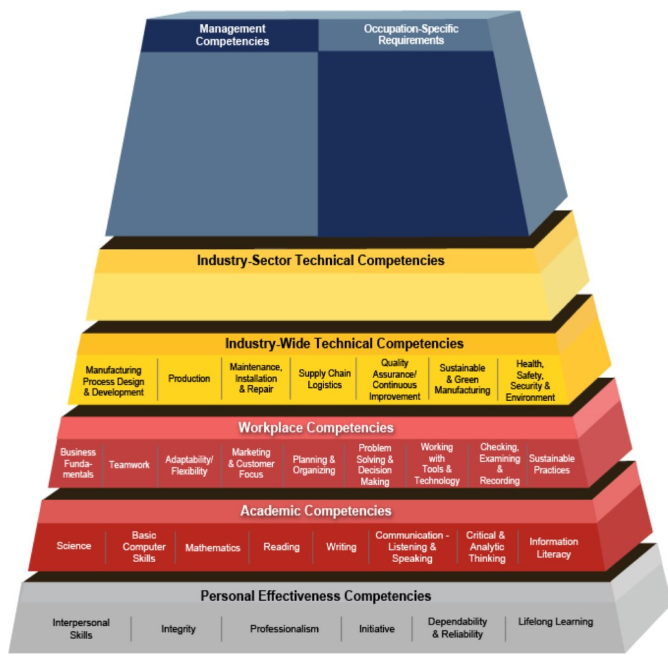

Figure 1. DOL's Updated Advanced Manufacturing Competency Model [2]

***Note*. Reprinted with permission from the U.S. Department of Labor/Employment and Training Administration**

A primary goal of the AMCM was to provide a framework for addressing the growing needs for a skilled manufacturing workforce. An SME report, "Using Competency Models to Drive Competitiveness and Combat the Manufacturing Skills Gap," defined the difference between competency and competency models, explained the different competency models, and explored best practices [3]. According to the report, American manufacturers are struggling to find qualified skilled workers to fill jobs. In 2013, an SME survey [4] stated "9 out of 10 manufacturers are having difficulty finding skilled workers; 64% of manufacturers say productivity losses are a result of a skills gap; 56% report the gap in skilled labor has impacted their company's ability to grow; and 78% cited a lack of qualified candidates as one of the top two factors that impacted their ability to hire a skilled workforce." Consequently, U.S. manufacturing industries began to view the AMCM more seriously, and manufacturing associations in many states published papers calling for urgent action. They also urged universities and community colleges to consider aligning their manufacturing education with the model.

Literature Review

As cited by the Manufacturing Institute [5], advanced manufacturing creates the highest number of jobs, pays higher wages than other industries, is critical to the economy, and represents more than 50% of U.S. exports. Thus, developing a workforce to meet the increasing future demand for manufacturing jobs is essential. Different manufacturing organizations and state manufacturing associations have published white papers that provide guidelines and recommendations to meet the increasing challenge of developing a manufacturing workforce with the desired skillsets and competencies.

The AMCM and SME four-pillars model are two models recommended as frameworks for academic institutions. Rietzke [6] discussed the AMCM's significance in training a manufacturing workforce with requisite skillsets and knowledge, and urged educators and training providers to develop curricula based on the model. He further suggested that those skillsets be taught at the college level to enable students to find good jobs with advancing career pathways. Manufacturing associations and manufacturing advocates should promote the development of competency-based education so that students possess the skills required by industry. Lehigh Valley Workforce Investment Board, Inc. [7], in partnership with the Pennsylvania Department of Education Bureau of Postsecondary and Adult Education, published a report urging the necessity of collaboration among educational institutions and manufacturing industries in the region to develop the next generation manufacturing workforce with skillsets suggested in the AMCM. The report also discussed manufacturing career pathways based on the NAM-endorsed Manufacturing Skills Certification System, analyzed the gap in the skillsets necessary for those career paths, and suggested possible actions for educational institutions and industries.

Jackson [8] investigated how the state of Massachusetts viewed the manufacturing sector, as leverage for statewide economic planning, how manufacturing industries should align with the AMCM, and provided educators and state leadership with guidelines on how secondary and postsecondary institutions could collaborate with the manufacturing industry to develop curricula that would create the future manufacturing workforce. The San Diego Workshop Partnership [9] conducted a research study documenting growing opportunities in the advanced manufacturing sector by analyzing job postings, employer survey responses, employment statistics, and focus groups of educational and training providers and employers. The study provided a detailed analysis of the job growth, skills gaps, and need for necessary training in advanced manufacturing. The research also identified specific actions needed by employers and educators, and provided guidelines based on the AMCM for San Diego manufacturing industries. The partnership recommended that the AMCM minimize the gaps in skillsets for manufacturing professionals and the potential workforce.

In a report to the Northwest Indiana Fund, the Taimerica Management Company [10] identified the competencies and skillsets required for the three largest employment clusters of Northwest Indiana, including advanced manufacturing, transportation and logistics, and insurance companies. In compiling the competencies, they used the AMCM as a foundation for their proposed model. The report found that manufacturers had difficulty in finding workers with satisfactory abilities at all levels. Therefore, the manufacturing programs in Indiana needed to address those gaps in skillsets among the new graduates and train them with regard to the AMCM model.

In addition to those studies on advanced manufacturing, several other research studies examined the requirements of advanced manufacturing competencies among the potential workforces. Darbanhosseiniamirkhiz and Ismail [11] investigated the influential factors that led to the adoption of the advanced manufacturing technology (AMT) model by SME. They also identified the challenges that medium and small manufacturing companies have to overcome in order to accomplish the goals of advanced manufacturing technology utilization. They analyzed previous studies on advanced manufacturing technologies and proposed a model for determining factors for the adoption of AMT.

Barber and Tietje [12] investigated competency requirements for technology managers in manufacturing, assembly, and materials processing functions. They identified 14 essential competencies for manufacturing management professionals. The findings from the study indicated that in order to be effective, manufacturing managers must possess a unique balance of interpersonal and leadership skills that are commonly associated with managers in general, as well as a significant depth of technical knowledge and skills about engineering, design, manufacturing, and operations. Lowden et al. [13] surveyed employers and post-secondary schools on their perceptions of graduates' skills and knowledge. The results indicated that both employers and schools expect graduates to possess required technical and subject-related competencies, as determined by their chosen degrees. Additionally, employers expected graduates to have competencies such as problem-solving abilities, teamwork, communication, leadership, and critical thinking. Their research advocated the establishment of programs that develop hands-on experiences and learning directly related to work.

Several educators and researchers have assessed their curricula against the SME four-pillars model and suggested curricular alignment with the model. According to Mott et al. [14], academic curricula should incorporate the four pillars, and instructors should use them to assess the level of student academic performance. Nutter and Jack [15] conducted a survey among industry practitioners, managers, company owners, and educators on the applicability of the SME four pillars in manufacturing curricula. The participants were asked to indicate how important each topic was for graduates of these programs. Based on the survey responses, the study recommended that manufacturing programs prepare their graduates based on the demands of industry and align their curricula with SME's four pillars to fill the gaps in the skillsets. Doggett and Jahan [16] conducted a survey among the students, faculty, and industrial advisory board members of an advanced manufacturing program to investigate the knowledge of SME's four pillars and to identify the skillsets required for an entry-level technology manager. The study concluded that non-technical skills are as important as technical skills for an entry-level manufacturing manager.

Very few studies have explored assessing or revising curricula in light of the advanced manufacturing model. Kirkwood Community College [17] made extensive use of the AMCM in developing curricula for associate degree programs in advanced manufacturing and robotics technologies. The college used the AMCM in collaboration with faculty and their industrial advisory board to close skills gaps and engage the group in developing a new curriculum. They also urged collaboration among the colleges and universities across the state to develop a common core curriculum focusing on the AMCM. A review of the literature suggests that, although manufacturing associations have published many papers on the necessity of the advanced manufacturing model, very few studies have assessed curricula against the model. It is, therefore, important that universities and community colleges assess their manufacturing programs against the AMCM, and seek alignment to reduce potential gaps in the skillsets necessary for entry-level manufacturing professionals.

This current study evaluated a manufacturing program against the AMCM, based on the perceptions of students, faculty, and industrial advisory board members of the program. The survey asked about the knowledge required for an entry-level manufacturing professional. Specifically, the survey sought to answer the following research questions:

- What competencies of the AMCM are the most important for entry-level manufacturing professionals?
- What competencies of the AMCM are the most frequently covered in the manufacturing program?
- Is the advanced manufacturing competency model compatible with what is being taught in your manufacturing program and the competencies that are important for an entry-level manufacturing professional?

The study examined a specific manufacturing engineering technology program. Students of the program take both technical and managerial courses and complete general education science and trigonometry. Graduates of the program obtain a variety of positions in the manufacturing industry, including engineering, production management, quality, and maintenance jobs.

Research Method

A survey, developed using the Web-based software Qualtrics, was sent to approximately 80 students and alumni of the advanced manufacturing program. Forty-four (55%) initially responded, with 14 (17%) completing the entire survey. The questions were based directly upon the AMCM model's first four levels of competencies: 1) personal effectiveness; 2) academic; 3) workplace; and, 4) industry-wide technical entry-level. For each level, respondents were asked to rate each competency on a scale from 1 to 5, with 5 representing the most important competency and 1 the least important. In addition, respondents were asked to rate each competency, with 5 representing the most frequently covered in their manufacturing program and 1 representing the least covered. Each competency level or tier (four levels) included the following two questions (eight questions total):

- Rate the following as most important (5) to least important (1) for an entry-level manufacturing professional.
- Rate the following from most covered (5) to least covered (1) for your manufacturing program.

An additional question, using a Likert scale (with 5 being strongly agree and 1 being strongly disagree), asked respondents to indicate their perception of the following statement:

- Is the advanced manufacturing competency model compatible with what is being taught in your manufacturing program and the competencies that are important for an entry-level manufacturing professional?

Results

Table 1 and Figure 2 show the findings of the survey. For the personal effectiveness competencies, respondents rated initiative and dependability/reliability highest in importance, with integrity having the most coverage. Lifelong learning was perceived lowest in importance and professionalism least covered. Table 2 and Figure 3 show the following results: For the academic competencies, respondents rated communication—listening and speaking—as highest in importance, with mathematics having the most coverage. Science was perceived lowest in importance and basic computer skills as least covered. Table 3 and Figure 4 show that, for the workplace competencies, respondents rated problem solving and decision making highest in importance and teamwork as having the most coverage. Sustainable practices were perceived lowest in both importance and coverage.

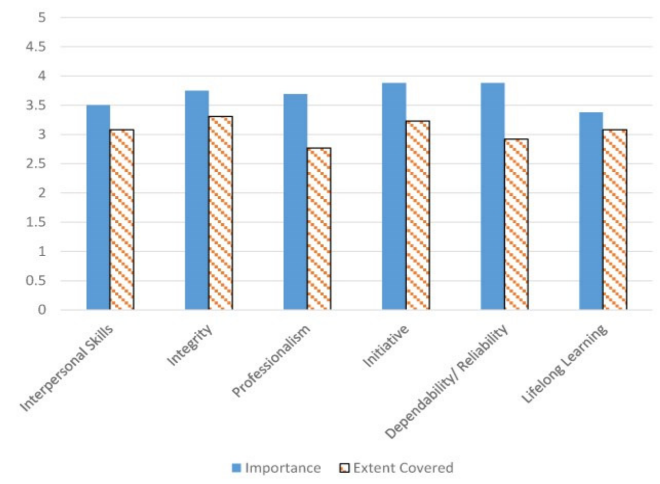

Figure 2. Personal Effectiveness Competencies: Comparison of Importance to Extent Covered

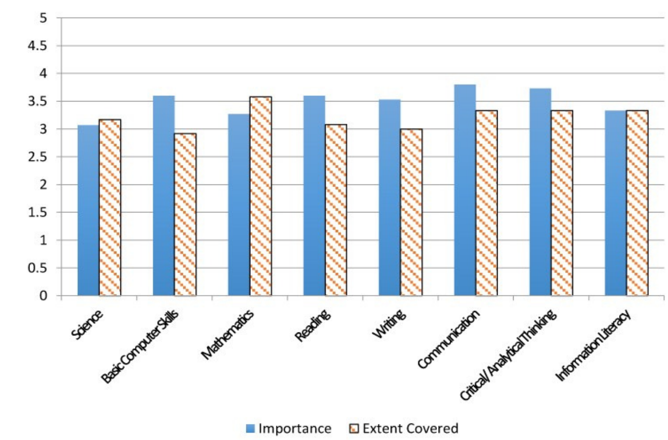

Figure 3. Academic Competencies: Comparison of Importance to Extent Covered

Table 1. Personal Effectiveness Competencies: Responses to the AMCM [2]

	Perceived Importance	Extent Covered		
	Mean	Std Dev	Mean	Std Dev
Interpersonal Skills: Demonstrating the ability to work effectively with others.	3.5	1.26	3.08	1.04
Integrity: Displaying accepted social and work behaviors.	3.75	1.24	3.31	1.38
Professionalism: Maintaining a socially acceptable demeanor.	3.69	1.2	2.77	1.01
Initiative: Demonstrating a willingness to work.	3.88	1.41	3.23	1.54
Dependability & Reliability: Displaying responsible behaviors at work.	3.88	1.45	2.92	1.32
Lifelong Learning: Displaying a willingness to learn and apply new knowledge and skills.	3.38	1.15	3.08	1.19

Table 2. Academic Competencies: Responses to the AMCM [2]

	Perceived Importance	Extent Covered		
	Mean	Std Dev	Mean	Std Dev
Science: Knowing and applying scientific principles and methods to solve problems.	3.07	1.1	3.17	1.03
Basic Computer Skills: Using a personal computer and related applications to convey and retrieve information.	3.6	1.3	2.92	1.16
Mathematics: Using mathematics to solve problems.	3.27	0.96	3.58	0.79
Reading: Understanding written sentences and paragraphs in work related documents.	3.6	1.06	3.08	0.9
Writing: Using standard business English, defined as writing that is direct, courteous, grammatically correct, and not overly casual. The main requirement of workplace writing is clarity.	3.53	1.19	3	1.04
Communication—Listening and Speaking: Giving full attention to what others are saying and speaking in English well enough to be understood by others.	3.8	1.21	3.33	1.07
Critical and Analytical Thinking: Using logic, reasoning, and analysis to address problems.	3.73	1.16	3.33	0.65
Information Literacy: Functional and critical thinking skills related to information, media, and technology.	3.33	0.98	3.33	0.89

Table 3. Workplace Competencies: Responses to the AMCM [2]

	Perceived Importance	Extent Covered		
	Mean	Std Dev	Mean	Std Dev
Business Fundamentals: Knowledge of basic business principles, trends, and economics.	3.13	1.06	3.25	1.06
Teamwork: Working cooperatively with others to complete work assignments.	3.93	1.22	3.75	0.97
Adaptability/Flexibility: Being open to change (positive or negative) and to considerable variety in the workplace.	3.93	0.96	3.15	0.9
Marketing and Customer Focus: Actively looking for ways to identify market demands and meet the customer or client need.	3.33	0.98	3	0.74
Planning and Organizing: Planning and prioritizing work to manage time effectively and accomplish assigned tasks.	3.93	0.88	3.25	0.62
Problem Solving and Decision Making: Applying critical-thinking skills to solve problems by generating, evaluating, and implementing solutions.	4.13	1.06	3.67	0.98
Working with Tools and Technology: Selecting, using, and maintaining tools and technology to facilitate work activity.	3.93	0.8	3.42	1
Checking, Examining, and Recording: Entering, transcribing, recording, storing, or maintaining information in written or electronic/magnetic format.	3.4	0.63	3.17	1.03
Sustainable Practices: Meeting the needs of the present without compromising the ability of future generations to meet their own needs.	3	0.85	2.75	0.75

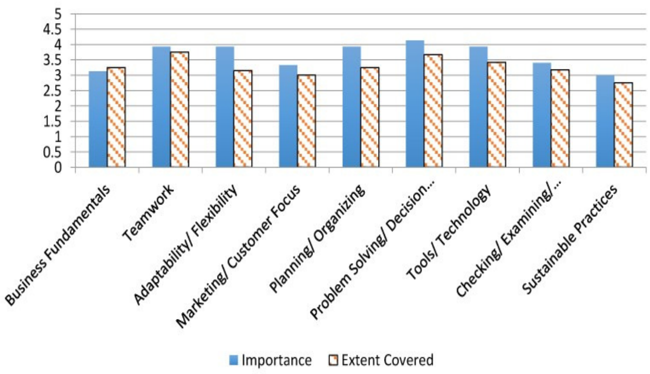

Figure 4. Workplace Competencies: Comparison of Importance to Extent Covered

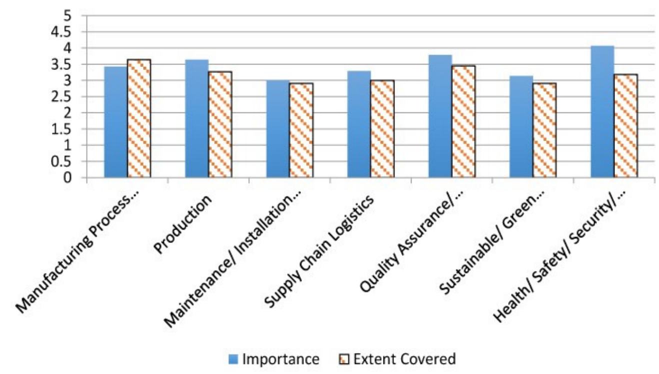

Figure 5. Industry-Wide Technical Competencies: Entry-Level Comparison of Importance to Extent Covered

Table 4 and Figure 5 show the last level surveyed, industry-wide technical competencies for the entry-level employee. Respondents perceived health, safety, security, and environment highest in importance, and manufacturing process design and development as having the most coverage. Maintenance, installation, and repair were rated the lowest in both importance and coverage. Sustainable and green manufacturing were also rated least covered.

The last question (question 9) asked the following: On a scale of 1 to 5 (with 5 being strongly agree and 1 being strongly disagree), indicate your perception of the following statement:

- Is the advanced manufacturing competency model compatible with what is being taught in your manufacturing program and the competencies that are important for an entry-level manufacturing professional?

Table 4. Industry-Wide Technical Competencies: Entry-Level Responses to the AMCM [2]

	Perceived Importance	Extent Covered		
	Mean	Std Dev	Mean	Std Dev
Manufacturing Process Design/Development: Research, design, implement, and continuously improve the manufacturing process to ensure product meets customer needs.	3.43	1.22	3.64	1.21
Production: Set up, operate, monitor, control, and improve manufacturing processes and schedules to meet customer requirements.	3.64	1.22	3.27	1.01
Maintenance, Installation, and Repair: Maintain and optimize manufacturing equipment and systems.	3	1.18	2.91	0.83
Supply Chain Logistics: Plan and monitor the movement and storage of materials and products in coordination with suppliers, internal systems, and customers.	3.29	1.07	3	1.26
Quality Assurance and Continuous Improvement: Ensure product and process meets quality system requirements as defined by customer specifications.	3.79	0.97	3.45	1.21
Sustainable and Green Manufacturing: Manufacture products using processes that minimize negative environmental impacts; conserve energy and natural resources; are safe for employees, communities, and consumers; and are economically sound.	3.14	1.03	2.91	0.94
Health, Safety, Security, and Environment: Employ equipment, practices, and procedures that promote a healthy, safe, and secure work environment.	4.07	1.07	3.18	1.4

Figure 6 shows that 64% of the respondents agreed or strongly agreed that the advanced manufacturing competency model is compatible with instructional content in their manufacturing program, and that the competencies were important for an entry-level manufacturing professional. Fourteen percent disagreed. Twenty-one percent neither agreed nor disagreed. No respondent strongly disagreed with the statement.

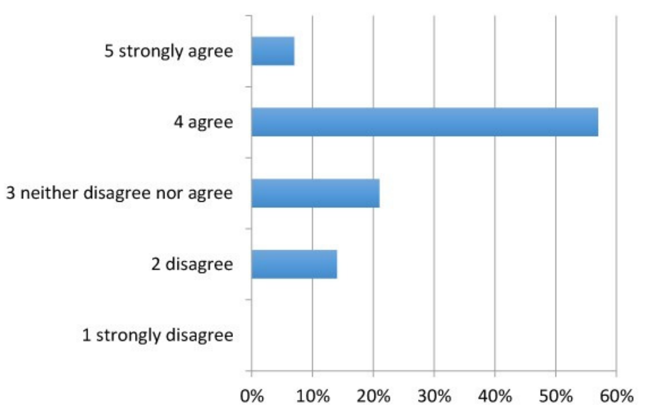

Figure 6. Percent of Respondents that Agree or Disagree that the AMCM is Compatible with Their Manufacturing Program and the Competencies Are Important for an Entry-Level Manufacturing Professional

Conclusions

For personal effectiveness, respondents perceived all competencies as being of greater importance than the coverage received during their manufacturing programs. Of particular interest was the disparity on professionalism, the maintaining of a socially acceptable demeanor, which respondents rated second highest in importance but lowest in coverage. Also noted was a difference in dependability and reliability, displaying responsible behaviors at work, which was one of the highest in importance and rated second lowest in coverage. These results may indicate that the manufacturing program needs to reinforce all of these competencies as part of the curriculum, and pay greater attention to professional demeanor and responsible behaviors.

At the academic level, respondents perceived five of the eight competencies as having greater importance than the coverage, with two of the competencies having more coverage than importance. Information literacy importance matched coverage. Science and math were rated higher in coverage than importance. Of interest was the difference in basic computer skills; that is, the ability to use a personal computer and its related applications in order to convey and retrieve information. It was rated lowest in coverage but high in importance, along with communication, critical/analytical thinking, and reading. These results may suggest that students are not as well prepared in computer literacy. The results may also imply that more attention should be paid to reading and writing competencies, which could be related to general literacy and the processing of meaningful information into knowledge. If the basis for manufacturing programs is strong competency in math and science, a close corollary is communication—listening and speaking—skills, typically supported by an ability to read, write, and think well. Thus, the program may want to consider giving greater attention to reading, oral, and written communication.

In workplace competencies, respondents rated all higher in importance than coverage, except for business fundamentals. Of interest was the response to adaptability/flexibility, which is being open to change and variety in the workplace. This was perceived as one of the highest in importance, but lower in coverage. The next highest gap was in the perception of planning and organizing, such as managing time effectively to accomplish assigned tasks. Curiously, these competencies may be two sides of the same coin, as adaptability and flexibility are generally required when plans and organization do not occur as intended. The program may want to place more emphasis on work and time prioritization and managing change in the context of the other competencies. For industry-wide technical competencies at the entry-level, respondents perceived slightly more importance than coverage for all competencies except manufacturing process design and development. The largest perpetual gap was in health, safety, security, and environment, which involves the use of equipment, practices, and procedures to promote a safe work environment. Respondents rated this highest in importance, but one of the lowest in coverage. The manufacturing program may want to add more content to existing courses for safety, ergonomics, and the environment.

Almost two-thirds of the respondents agreed that the AMCM is compatible with what is being taught in the manufacturing program and the competencies that are important for an entry-level manufacturing professional. Contrarily, slightly over one-third of the respondents neither agreed nor disagreed with the statement. This may indicate that the current perceived gaps between importance and coverage of the advanced manufacturing competencies could be narrowed and potentially produce better-prepared entry-level manufacturing professionals. In summary, an increased emphasis on professionalism and responsible behaviors with greater attention to thinking, reading, oral, and written communication might improve academic performance and personal effectiveness. In terms of competencies that would benefit respondents in the manufacturing workplace, program administrators should consider increased attention to planning and organizational skills, coupled with lessons on adaptability. Finally, the program should evaluate if a greater amount of content on equipment, practices, and procedures for a safe work environment would be beneficial. Overall, for this manufacturing program, survey results indicated that the advanced manufacturing competency model was perceived as being compatible with the desired competencies for an entry-level manufacturing professional.

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ROBOTICS AND AUTOMATION PROFESSIONAL DEVELOPMENT WORKSHOP FOR FACULTY

Aleksandr Sergeyev, Michigan Technological University; Nasser Alaraje, Michigan Technological University

Abstract

Educators have constantly been searching for the most effective strategy to improve student learning outcomes in a diverse spectrum of educational programs. Exploiting the demand for robotics in many industrial fields is an approach that can lead to an increase in interest in STEM. The widespread use of robotics across industrial and research fields makes robotics a useful STEM educational tool. Nowadays, the field of industrial robotics is contingent on workforce with relevant skills necessary to sustain and use existing robots and augment future robotics technologies. To supply industry's demand for robotic specialists, educational institutions should adequately respond by developing appropriate curricula for the students and industry representatives in the field of robotics and automation. This current NSF-sponsored project presents a new methodology for industrial robotics in Electrical Engineering Technology (EET) programs at Michigan Technological University and Bay De Noc Community College. The main goal of the proposed activities is to develop a curriculum model in industrial robotics that can supply graduates with the skills that are up-to-date and relevant to current industry needs.

In this paper, the authors describe an integral part of this project's dissemination effort—a 2-day faculty workshop aimed at providing an excellent professional opportunity for faculty members from other institutions, who need to revamp their skills in robotics automation. The workshop will share combined knowledge gained through curriculum development with technical information from specific lab procedures. In addition, participants will learn how FANUC robotics training can be integrated with practical curricular and educational strategies for developing courses similar to those established under collaboration of two- and four-year degree academic institutions.

Project Background

Automation is blooming in all sectors of the industrial world, which in turn, drives job creation and is clearly outlined in a study by the market research firm, Metra Martech [1]. Technological advancements have replaced low-skilled jobs and increased the efficiency of production all across industry. Studies have reported that the jobs lost to robots are much fewer than the jobs created by them. For example, in 2011, the estimated number of jobs created by robotics worldwide was about four to six million, and the numbers rise to eight to 10 million, counting indirect jobs. International Federation of Robotics (IFR) projects [2] that robotics will generate about 1.9 to 3.5 million jobs in the coming eight years. The rapid evolution of robotics and automation, especially during the last few years, and the future projections for their impact on the U.S. economy are very encouraging. According to Metra Martech [1], even by conservative estimates, the number of robots used in industry in the U.S. has almost doubled in recent years.

In the manufacturing sector, recent growth was 41% in just the last three years. Research by Metra Martech [1] illustrated that from 2014 to 2016, robot installations were estimated to increase about 6% a year, resulting in an overall 3-year increase of 18%. Likewise, companies that manufacture industrial robots have reported a rapid growth of 18-25% per year in their sales and revenue. Even though jobs will be displaced by the increasing use of robots, their growing demand will force the robot manufacturers to roll out more and more jobs. It has been observed that, due to advancements in robotics, the jobs lost to developing countries are now declining and the developed countries are able to create employment. For example, Hughes [3] covered in an article that Apple has invested $10.5 billion on machines and robots at their manufacturing plant in the U.S. that produces the Mac Pro. In March of 2012, Amazon was able employ 20,000 people in its U.S. fulfillment centers, as they had deployed 1382 kiva robots to automate their warehouses.

The rise of robotic automation in many sectors of industry demands highly trained professionals being able to monitor existing robots, conduct research on future robotic know-how, and to educate the future workforce on various robotic solutions. Therefore, it is crucially important that educators effectively respond to the rapidly growing demand for robotics experts by developing the curricula geared towards teaching these high-demand skills in robotics and automation. Also, certified robotic manufacturers authorized training centers (CRTC's) are in high demand and needed for retooling industry representatives and displaced workers. In this paper, the authors address an effective approach for teaching evolving matters of industrial robotics in EET programs and at different educational levels.

Educational Need

Robotics is a great tool for helping to promote numerous STEM topics. Educators certainly have been making measurable progress toward improving STEM education, from primary to tertiary levels, but continuing challenges remain. The interdisciplinary nature of creating robots makes it a valuable pedagogical tool for teaching many STEM areas. The novelty of robotics is instrumental in attracting and recruiting diverse STEM students: robotics can be used to introduce various skills needed to pursue diverse STEM career paths [4, 5]. Robotic solutions promote comprehension of both scientific and mathematical principles, enhance problem-solving techniques, and encourage cooperative learning [4, 6, 7].

More and more robots are designed to perform tasks that human used to perform and often in non-safe of pleasant conditions. Robots have changed the lives of amyotrophic lateral sclerosis (ALS) patients by giving them the ability to speak after their vocal cords have failed, and have sparked our imagination in space exploration (not to mention our fascination with characters like R2D2). As many have put it, robots do our dirty, dangerous, and/or dull work. Millions of domestic/personal robots have been introduced worldwide, from lawn mowers to entertainment robots [8]. As a result, popular interest in robots has increased significantly [5, 6, 9, 10]. However, the automotive industry was the first to utilize robotic solutions, nowadays the other sectors of industry such as aerospace, machining, and medical also rely on robotic automation [11].

Robotics can be used as an interdisciplinary, project-based learning vehicle to teach STEM fundamentals. Understanding the valuable role robotics education plays in helping students understand theoretical concepts through invention and creation, many universities include components of robotics research in curricular offerings. It is widely recognized that robotics is a valuable learning tool that can enhance overall STEM comprehension and critical thinking" [12]. As a result of these benefits and industry needs, new programs in robotics automation and applied mobile robots are popping up in the U.S. and abroad. Industrial help from companies such as Microsoft, FANUC Robotics America Inc., and MobileRobots Inc., is essential to the growth of these programs. The objectives behind robotic programs are clear: 1) in the short-term, robotics education fosters skills such as problem solving, communication, and teamwork. In addition, it develops independence, imagination and creativity [12- 18]; and 2) in the long-term, robotics education plays a key role in preparing a workforce to implement 21st century technologies. "Currently, only a few universities promote and offer specific undergraduate robotics degrees. For example, Worcester Polytechnic Institute (WPI), has offered a Bachelor of Science in Robotics Engineering since 2007. On the opposite side, universities have graduate degrees focused on robotics, including Carnegie Mellon University, MIT, UPENN, UCLA, WPI, and the South Dakota School of Mines and Technology (SDSMT). Michigan State University does have a well-designed robotics and automation laboratory but is also geared towards graduate robotics research" [13]. Regardless of the demand, only a few universities across the U.S. offer certification in robotics automation. With so few focused industrial robotics programs, undergraduate industrial robotics training often occurs in Electrical Engineering Technology (EET) programs, with the focus of the proposed program being EET.

Training in robotics automation is especially important to Michigan's economy. A major decline in automotive manufacturing jobs has left many areas in Michigan with high rates of unemployment. Baraga County, located 15 miles south of Michigan Tech, has one of the nation's highest rates of unemployment. Yet, Michigan has an unmet need for workers in robotics jobs [19]. Filling these jobs, however, requires workers trained and certified in the following skill sets: designing, testing, maintaining, and inspecting robotic components; troubleshooting robot malfunctions; using microcomputers, oscilloscopes, hydraulic test equipment, microprocessors, electronics, and mechanics; and reading blueprints, electrical wiring diagrams, and pneumatic/hydraulic diagrams. "Driven by industry needs, the new curriculum designed in this project will be adapted to both two- and four-year programs. This project aims to address the current need in the U.S. workforce for properly prepared STEM professionals, train current industry representatives and displaced workers in robotics automation, educate K-12 teachers about current industrial robotics technologies and promote STEM fields among K-12 students" [12].

Project Core

Michigan Tech has built a very strong, multi-faceted curriculum in robotics and automation. Figure 1 depicts in-place and developing coursework for two- and four-year degree institutions, high school teachers and students, industry representatives, and displaced workers. The block at the upper-left corner of Figure 1 shows two courses: 1) existing Michigan Tech and Bay de Noc Community College Real-Time Robotics Systems course and its derivatives, and 2) a new course in robotic vision. The block on the right side of Figure 1 demonstrates training curricula for students from other universities and community colleges, industry representatives, and displaced workers. The block at the bottom-left corner of Figure 1 outlines a robotics curriculum model for high school teachers and one-day hands-on camps for

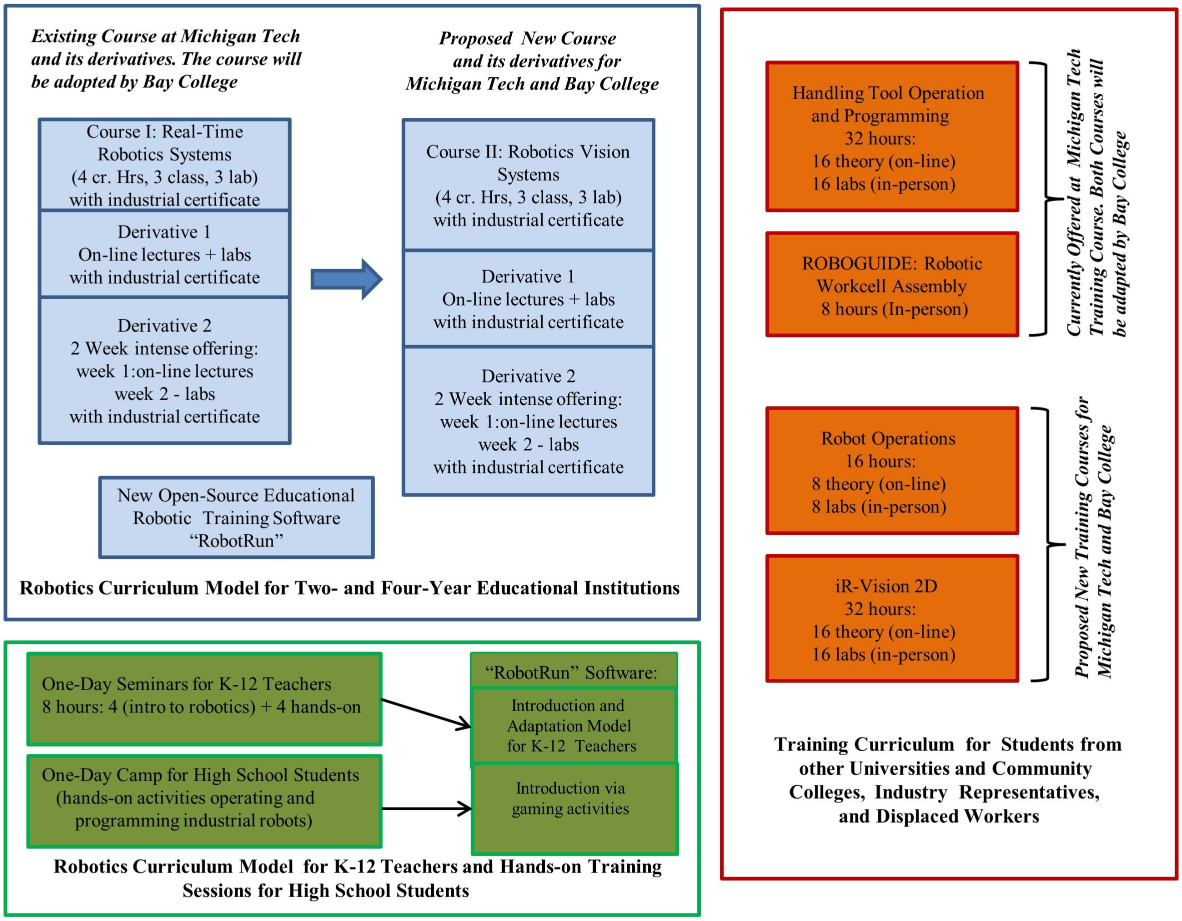

Figure 1. Proposed Robotic Automation Curriculum Development

high school students conducted as part of this NSF-sponsored project. The authors have previously provided a very detailed description [12, 13] for all of the curriculum models depicted in Figure 1; therefore, this information was omitted here. Though the project includes outreach to high schools, it was the authors' intention to focus this paper on the professional development opportunities in robotics automation for faculty members of two- and four-year institutions.

In addition to curriculum development, another important component of this work was a software program created for this project called RobotRun. The program activity utilizes a 3D animated rendering of a robotic arm that is controlled via an intuitive programming language similar to software used to program real robotic arms. The programming language in this robotic arm simulator software provides all of the basic commands that exist in real-world robotics systems so that students can easily transfer the knowledge gained from the software to real-world robotic arms.

The software allows the user to control where the end-effector should jog, at what speed and type of motion termination, how many times it should repeat the movement, and other common robotics controls. Besides the option of jogging the robot and performing programming tasks, the software can be configured to present users with different scenarios that mimic real-world industrial scenarios, such as pick-and-place, palletizing, welding, and painting. The program also allows users to load and save their programs so that they can turn them in to an instructor for grading. This new software provides all of the options necessary to teach required skills in robotics handling tool operation and programming. It is simple as well as intuitive, and omits the unnecessary features of expensive robotic simulation software packages designed for in-depth industrial simulations that are not typically used in educational settings.

An integral part of this project's dissemination effort are 2-day workshops for up to 12 faculty participants. The project PI has developed and will lead the workshops over the course of three years in collaboration with faculty from Bay College. The workshops are being offered for faculty members from Michigan Tech's partner community colleges (Macomb Community College, College of Lake County, and Northcentral Technical College), that have already established articulation agreements with the EET program, as well as interested EET faculty from other colleges and universities. The faculty workshops are scheduled to be conducted for three consecutive years at Michigan Tech and in Years 2 and 3 at Bay College. The main impetus behind the workshops is to share the combined knowledge gained through curriculum development efforts and the technical information derived from lab development experiences. In addition, participants learn how FANUC robotics training can be integrated into the curricula of their home institutions. These workshops are offered to faculty members of two- and four-year institutions, and are designed to increase practical experience in industrial robotics as well as renew interest in and empower those seeking to revamp existing courses or develop new courses in industrial robotics.

These 2-day, 16 contact-hour workshops are designed to be an intense, immersive experience that provides a broad spectrum of activities to participants. The workshop starts by conducting a survey and pre-test. The survey, an anonymous questionnaire, is designed to collect the participant's feedback regarding attitudes towards different modes (in-person, online, or blended) of knowledge delivery. The purpose of the pre-test is to assess participant's knowledge on the specific topics introduced during the workshop. During day one of the workshop, participants will be first familiarized with the structure of the curriculum developed at Michigan Tech and Bay de Noc. The theoretical topics covered during day one include: concepts of robotic safety in an industrial environment, overview of the FANUC robots utilized in the development of the curriculum, robotic frames and how they impact a robot's motion, various robotic end-effectors commonly used in industry, and effective programming of tool and user frames. In order to reinforce subject matter understanding, each theoretical topic covered during the workshop is followed by a hands-on activity. A total of three laboratory exercises are offered during the first day of the workshop.

Day 2 of the workshop starts by introducing the RobotRun educational robotic simulation software. A faculty member demonstrates its functionality, followed by participants being tasked to create several simulation projects. Theoretical topics covered during the second day of the workshop include: concept of robot programming, data and position register instructions, and how to use conditional and unconditional instructions to improve programming efficiency. The topics mentioned above are reinforced by three lab exercises. Day 2 of the workshop culminates with a survey, post-test, and closing discussions, during which time faculty members leading the workshop will provide recommendations on the possible implementation of this newly developed robotics curriculum at other institutions. A detailed agenda of the first faculty workshop conducted at Michigan Tech in Year 1 of the project is summarized below:

Day 1:

Topic 1: Industrial Environment Safety (30 min.)
Topic 2: Overview of LR Mate Fanuc Robot (30 min.)
Topic 3: Robotic Frames (1 hr.)
Participants tour the robotic automation lab and learn more about both the hardware and software necessary to establish a robotic automation lab at their respective institutions (1hr.).
Lab 1: Jogging in World and Joint Modes (1 hr.)
Topic 4: End-of-Arm Tooling (1 hr.)
Lab 2: Teaching Tool Frame (1 hr.)
Lab 3: Teaching User Frame (1 hr.)

Day 2:

Faculty participants familiarized with RobotRun educational training software. The faculty member leading the session will first demonstrate the functionality of the software, after which participants will be tasked to create several simulation projects (2 hrs.).
Topic 5: Robot Programming (1 hr.)
Lab 4: Basic Programming (1 hr.)
Lunch break 12:00-1:00
Topic 6: Data and Position Register Instructions (1 hr.)
Lab 5: Registers and Position Register Instructions (1 hr.)
Topic 7: Conditional and Unconditional Branching Instructions (1 hr.)
Lab 6: Conditional and Unconditional Instructions (1 hr.)
Survey/Post-Test
Discussions and Adjourn

The first workshop was advertised using engineering technology listservs and was filled within just fifteen minutes after posting the advertisement! An additional 45 faculty members from institutions all over the U.S. had to be put on a waiting list. This unquestionably indicates a high demand for robotic training, resulting from rapidly developing industrial automation (with robotics being in the top tier) across the entire industrial spectrum. It is the authors' goal to further increase awareness of robotic training available at Michigan Tech and Bay de Noc Community College via engineering technology listservs, conference proceedings, and journal publications. The resources developed for these faculty workshops and industry robotic training can be found in previous publications by the authors [20, 21].

Conclusions

There is significant demand from industry for well-prepared specialists capable of programming, maintaining, and troubleshooting modern robots. As a result, the goal of this project was to develop a model curriculum and the associated tools to address current and future robotics industry expectations. In addition to enhancing STEM education at the college level, this collaborative project provides a template for how other institutions can bridge the gap between academia and industry, and academia and K-12. These bridges are critical for providing new resources to recruit and prepare a sustainable pipeline of graduates in robotics automation. Short-term outcomes include: Models for outreach that encourage early STEM interest, two certificates endorsed by industry, and faculty development workshops to reach other universities and colleges.

Development of an advanced, industry-driven, hands-on educational curriculum in robotic automation targets to advance the value of STEM education for the students at two- and four-year institutions. The RobotRun software developed will be freely available for adaptation, which will allow robotics to be taught even when the purchase of industrial robots is not feasible. Faculty development includes familiarizing educational community with the developed resources as part of this NSF-sponsored project. In addition, faculty members from the other institutions receive extensive training on the RobotRun robotic software, affording them the opportunity to implement the software at their respective institutions. Developments and dissemination of all project activities will align Michigan Tech robotic automation education with industry needs. As a result of the project, university graduates will join the workforce well-prepared to tackle intricate and constantly evolving demands of tomorrow's high-tech automated workplace.

Acknowledgments

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TECHNOLOGY MANAGEMENT AS A TOOL FOR LEARNING OUTCOMES IMPROVEMENT

Irina Sergeyeva, Finlandia University, Aleksandr Sergeyev, Michigan Technological University

Abstract

Educators from different disciplines are always searching for the best educational approaches to improve student comprehension and learning. Some representatives of the educational sphere believe that the quality of education relies on the teaching approach, others claim that the students' responsibility and attitude toward the learning progression is the key element in the outcome of the educational program. Either way, the reason for constant argumentation and propagation of research is to find the most effective approach to the learning process. The cognitive, affective, and psychomotor domains of Bloom's Taxonomy guide the effective process of student transformation from the basic level of information comprehension to the upper level of creativity in the chosen field of education. Technology, on the other hand, provides a valuable tool for the stimulating learning environment implementation and serves as a connective element between educational theories and practical approaches to the learning process. In this paper, the authors outline influential factors on learning outcome improvement, emphasize the important role of technology in learning advancement, and provide an overview of the existing teaching methodologies implemented at Michigan Tech and Finlandia Universities.

Introduction

Technology revolutionized human comprehension in all stages of development. It became an inevitable part of human existence and social life management. Technology is part of communication, industrial process, the healthcare system, entertainment, and plays a crucial role in educational methodologies. Not that long ago, and due to the lack of technological development in portable electronics, knowledge transfer, as part of the educational process, was restricted to traditional methods of information delivery—educators had to use chalk and a blackboard to explain simple and different subject matter. Nowadays, technology is developing at an unmatched pace, providing a wide selection of electronic devices that can be incorporated in the classroom and virtual environments at different educational levels. The quality of learning outcomes is not related to the educational field, and is based on the methods of knowledge distribution, degree in technology management, and incorporation of Bloom's Taxonomy in the teaching process.

Introduction to Bloom's Taxonomy

The idea of a hierarchical approach to learning outcome improvement was recognized by a group of psychologists when Benjamin Bloom "set forth in motion the production of the Taxonomy of Educational Objectives, The Classification of Educational Goals, Handbook I: Cognitive Domain" [1], during a meeting of the American Psychological Association in 1948. The original classification system has been reviewed and redacted many times, growing from a single cognitive to multiple affective and psychomotor learning domains. The final revision of the handbook was accomplished by Anderson and Krathwohl in 2001. It was formally titled, "A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives" [1], giving the classification system a wider application in the education sector. Nowadays, this system of intellectual behavior in learning is known as Bloom's Taxonomy, and is widely utilized by educators and students.

The cognitive domain of Bloom's Taxonomy has been most widely utilized in the educational field. The concept is based on the progressive development of the learner's cognition, starting with simple memorization and continuing with the more complex skills of understanding, application, analysis, evaluation, and creation. To perform the higher level skills, according to Bloom's Taxonomy, learners have to implement the low-level skills. As an example, "to critically appraise the medical literature (evaluation), one must have knowledge and comprehension of various study designs, apply that knowledge to a specific published study to recognize the study design that has been used and then analyze it to isolate the various components of internal validity, such as blinding and randomization" [2].

The affective domain, on the other hand, refers to student emotions, "to touch the learner's heart to impact his or her learning" [3]. The emotional concept is an inseparable part of human nature and plays a significant role in the communication process. Emotions are contagious. Educators have been utilizing this knowledge to develop educational strategies, which would evoke enthusiasm, motivation, curiosity, and other positive feelings in students' minds in order to improve the learning outcome. Bloom's Taxonomy subdivides the affective domain into five hierarchical groups: receiving, responding, valuing, organizing, and characterizing.

The last component of Bloom's Taxonomy is the psychomotor domain. Even though the psychomotor domain is not as popular a subject for discussion in the educational sphere as the cognitive domain, it does create the connective element between mind and body. The psychomotor domain addresses learning outcomes that "emphasize some muscular or motor skill, some manipulation of material and objects, or some act which requires a neuromuscular coordination" [3]. The ability of students to perform a task based on good motor coordination is equally important in the engineering and health-related practices. Nursing students, for example, experience direct contact with hospitalized patients and gradually advance their level of psychomotor activity from basic to skilled movements. Engineering students are trained to operate robotic technology. Their capacity to perceive the technological innovation and adapt their skills to continuous industrial revolutionization is crucial to their future profession.

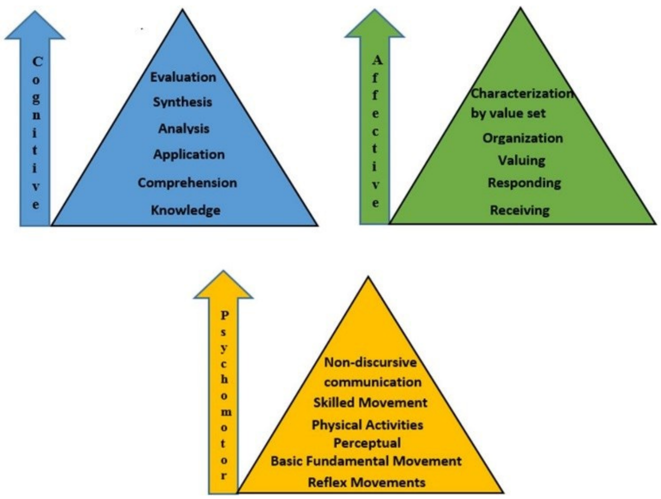

Figure 1. Three Domains of Bloom's Taxonomy

Three domains of Bloom's Taxonomy create a road map for managing the learning process in the contemporary educational environment. They are connected elements of progressive student development towards professionalism and confidence in working settings. The question is, who is going to follow this route and what is going to help the ventures to reach the final destination successfully? The answer to this question lies in the modern world of technology evolution.

The Role of Technology in Education Management

Utilization of technology in the educational sector has served as a tool to assist educators in reaching established teaching goals in more effective and efficient ways as well as accommodating learner needs. The diversity of existing technological innovation has allowed educators to create a wide variety of methods for cognitive, affective, and psychomotor progression of learning in on-campus and off-campus settings. Nevertheless, changes in the learning environment constantly challenge teaching professionals and prompt them to adapt to the accelerating pace of technology evolution and the new generation of adult students.

Changing Demographics of Students

Adult education has been experiencing significant demographic variations. The growing numbers and diversity in the student population in higher education can be explained by the globalization process and increasing interest in continuing education expressed by older adults. Anderson [4] noted that today "a third of undergraduate students are twenty-five years old and older." Since 1970, the number of older undergraduate students has "increased by 144 percent, whereas the number of students under the age of twenty-five increased by 44 percent" [4]. The mindset of the younger population of students is affected by the constant exploitation of online media. The virtual environment possesses the social life of this "net generation" of students. Worley [5] described this generation, students born between 1982 and 2002, as a period of time as "impatient, self-centered, extremely social, materialistic, and technologically advanced." The older population of students, on the other hand, is team oriented, prefer personal communication, and have multiple social responsibilities on top of school assignments. Work, community service, and family obligations are just some examples. Despite the fact that these students have less technological dexterity, virtual types of education may be a great convenience because of flexibility, which provides a choice for location, pace, and methods of the learning process.

A mix of several generations in the educational sphere has a great impact on the teaching institutions dictating new requirements and expectations. Educators should analyze the learners' characteristics, such as age, background, self-direction, and intrinsic motivation to apply Bloom's Taxonomy of learning and create a clear pathway that would guarantee the progressive growth of learners in the educational field. In addition, educators have to recognize the learners' needs and identify the relevance of the educational material and methods to the learners' experience.

Teaching Methodologies

Technological advancements and their quick evolution require students to be up-to-date and relevant with the skills they possess. In addition, in many cases, students are responsible for paying the high cost of education, which obligates them to work in order to secure funds. And working, in parallel to attending college, creates a very busy and difficult schedule for students. Providing flexibility in class offerings should help many students in need to attend and successfully finish college without compromising their work. To expand educational opportunities for students, educational institutions must develop various curricular models that allow students to learn via traditional, blended, or purely online class styles.

Educational Models

Figure 2 represents traditional, blended and online educational models that currently exist and which are practiced by academic institutions. In traditional models, the theory and laboratory exercises are delivered by the faculty member in-person. Blended learning delivers a mix of in-person and online representation of the subject matter. The idea behind blended learning is to combine the best approaches of in-person and online education in a single model.

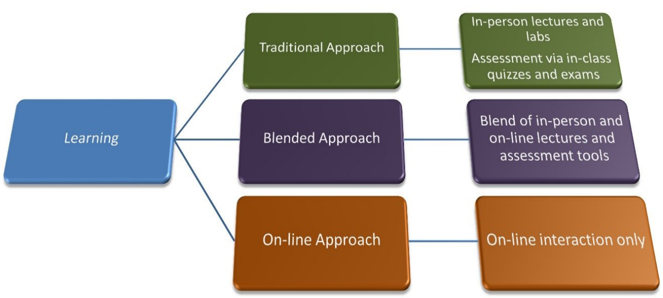

Figure 2. Traditional, Blended and Online Educational Models

The online part of a blended course provides learners with the necessary theoretical background of the subject, while in -person interaction can engage them in active educational scenarios and brain-storming sessions to enhance their interaction with each other and the faculty member. There is also evidence that the blended instructional approach can "result in learning outcome gains and increased enrollment retention" [7]. Nowadays, blended learning is one of the most common teaching modes. In the online educational approach, the subject matter is delivered via the Internet, and may include media in the form of text, image, animation, streaming video, and audio. "By 2006, 3.5 million students were participating in online learning at institutions of higher education in the United States" [8]. According to the Sloan Foundation reports [9, 10], the online learning in post-secondary education has increased 12-14% during the 2004-2009 time period. Online education provides tremendous flexibility for students not able to attend college, due to the work load. It also provides an opportunity for self-learners preferring to pursue higher education at their own pace. Currently, many traditional programs included an online option of taking courses and even securing specific degrees [6, 11, 12]. Educational research shows that students' perceptions of online education, their participation, and motivation are different in online courses [6, 13-15]. "Positive attributes of online learning include: increased productivity for independent learners; diminished fear of public speaking, which increases class participation; efficiency in assignment completion; and easy access to all lecture material during the entire course" [11]. It has also been shown that online learning reduces the active process of learning [6, 11, 16]. Various demographic groups perceive online education differently—older students have significantly higher performance compared to their younger peers [6].

Educational Model Preference

Educators from different disciplines are always searching for the best educational approaches to improve student comprehension and learning. In-person teaching represents static lecture-discussion formats [16, 17] resulting in graduates not having a full range of employable skills and abilities in order to apply the knowledge skillfully, communicate effectively, and work in teams. On the other hand, educational research [18, 19] shows that active learning involves all three components of Bloom's Taxonomy and significantly improves student comprehension and proficiency in the subject matter [6]. The U.S. Department of Education reports that blended learning education produces statistically better results than their in-person equivalents [20]. Students also respond to the value of the blended course delivery models. "An Eduventures survey of 20,000 adult students found 19 percent of responders were enrolled in blended courses" [21]. "However, 33 percent of all respondents cited it as their preferred format" [22]. However, the theory behind the subject matter is the required component of the educational process; students greatly benefit from active learning techniques as part of blended courses. The tendency of students to value (affective domain) the blended methodology of education leads to more effective ways of conceptual development, thereby positively influencing the learning outcomes. What still remains unclear is the "gold standard" for pedagogical approaches and the question that needs to be answered: Where is a "gold" balance between the statically transmitted information and how much knowledge can be delivered via active learning techniques? Another important question is: How can current advances in technology assist educators in course development and delivery?

Technology Use in Engineering and Health Science Educational Fields

A detailed description of various teaching methodologies and technology utilization to accommodate these methodologies will be presented with specific examples of Finlandia and Michigan Technological Universities. It is the authors' intention to not only provide details on the current teaching methodologies used in the health science and technical departments of respective universities, but also draw a line between how similar technological tools can be effectively used to deliver educational curricular.

"Michigan Technological University is a public university committed to providing a quality education in engineering, science, business, technology, communication, and forestry. Michigan Tech is rated highly for academics, career preparation, and quality of life in the Princeton Review's Best 379 Colleges 2015 Edition. Michigan Tech is ranked in the top tier of national universities according to the U.S. News & World Report's 'America's Best Colleges'" [23]. Employers, especially in the state of Michigan, have consistently relied on Michigan Tech to deliver experiential educational opportunities. [23]. Over 70% of Michigan Tech students are enrolled in engineering and technology programs. Cumulatively, the School of Technology (SOT) and College of Engineering (COE) graduated 1060 undergraduate degrees in AY2014-2015, or 67% of the total degrees.

Twenty-two research centers and institutes support interdisciplinary research, partnerships with industry, and collaboration with community and informal education organizations. "The SOT awards bachelor's degrees in Computer Network and System Administration, Construction Management, Electrical and Computer Engineering Technology, Mechanical Engineering Technology, and Surveying Engineering—all degrees that require an understanding of robotics" [23]. Employers, especially in the Midwest, rely on the Michigan Tech to deliver experiential educational opportunities; more than 350 companies recruit on campus annually, and Michigan Tech students average five interviews before graduation. Michigan Tech has a 96% job placement rate.

Finlandia University, the only private university in the Upper Peninsula of Michigan, has deep historical roots. Since its establishment as a seminary in 1896 with the purpose of preserving Finish culture, it has gradually evolved into a four-year college with a wide diversity of programs: International School of Art and Design, International School of Business, Suomi College of Arts and Sciences, and the College of Health Sciences. Because of its affiliation with the Evangelical Lutheran Church of America, Finlandia University's mission is not only to help students achieve academic excellence, but also to dedicate its existence to spiritual growth and service [24]. "More than 485 students from 25 states and six countries attend Finlandia. About 39% live on campus; 43% are male, 57% are female; 14% are minority students; and about 96% are seeking bachelor degrees" [24]. Faculty from both universities actively utilize various technological tools to create advanced teaching methodologies. A significant number of courses at Michigan Tech and Finlandia are still taught using the traditional approach; however, for the past few years, more and more different derivatives of teaching have been observed.

Technology Utilization at MTU

Michigan Tech is constantly evolving in its use of technologically advanced solutions, which not only allow instructors to make recitations more interactive but also promote in-depth assessment of student subject perception and comprehension. Technology implementation in the classroom environment also often allows instructors to collect instant feedback from students and adjust teaching accordingly. The instructors at Michigan Tech are starting to focus on breaking up lectures by using a variety of interactive methods and technologies. By far the most common technology used in the classroom environment is clickers [25], which allow students to respond to multiple-choice questions. Some instructors utilize them as a reading "quiz," but far more are using them in a method called "Peer- Instruction," in which students first answer on their own and then discuss the question. Some instructors have also begun experimenting with phone/tablet/laptop-based response systems such as Nearpod [26], which allows text and picture responses in addition to multiple-choice polls.

Instructors are also making extensive use of small student whiteboards for collaborative, small-group exercises such as brainstorming, simple problem solutions, drawings, etc. The advantage of using a whiteboard is that students can hold them up so an instructor can quickly check answers and/or make sure students are on the right track, and then adjust teaching accordingly. With a single marker/eraser, students in a group must discuss what goes on the board. This has become so popular that several classrooms now have boards mounted on walls, and some departments have invested in carts full of boards that are wheeled between classrooms. Other innovations include group quizzes, both conventional and using the Immediate Feedback Assessment Techniques (IF-AT) [27], which are similar to lottery scratch-off tickets. Group quizzes are often used either just before (as a review) or just after an exam. Students in a group must agree on a single answer, which results in extensive discussion (and learning) as answers are justified.

Outside of the classroom, instructors make extensive use of the Canvas Learning Management System (LMS) [28]. Students are often asked to work through a series of pre-class readings, videos, or other content, and then must take a quiz within the system. Quizzes can simply measure students understanding to give an instructor insight into how class time would best be used, or set so that students must meet a minimum level of mastery before progressing to the next activity. This flipped classroom model encourages the delivery of content outside the classroom and more analytical, in-depth work on problems or exercises during class, often using the interactive methods enumerated above. Canvas also hosts discussion boards on which students can be required to post reflections, questions, or comments, and interact 24 hours a day. These can be used as homework help boards, for discussion about projects, or pre-class reflections on reading. Most assignments are now submitted, graded, and returned through Canvas (including markup and comments), and software checks for plagiarism automatically if desired. The Google Docs/Drive system is also used for student collaboration in a wide variety of ways, from aggregating lab results to collaborative presentation creation. When combined with online conferencing options (Big Blue Button, Google Hangouts, or GoToMeeting), a completely online collaborative environment is used in some online sections.

The Panopto video streaming system [29] has made making both lecture-capture and other videos easily available to students. Michigan Tech now has more than 30 campus-wide classrooms in which voice and video recording can be scheduled to automatically take place and be posted for students. Instructors can also more intentionally create video lectures or problem solutions on a computer (using voice-over-PowerPoint), on a document camera, or in front of a whiteboard. Problem solutions are especially aided by a small robotic device, called a Swivl, on which a tablet or phone can be placed. The Swivl then tracks a blue-tooth connected marker and microphone worn around the neck to create a video that follows the instructor as she/he moves throughout the classroom.

Technology Utilization in Finlandia Health Science Programs

A wide diversity of technology has been utilized in the Finlandia Health Science programs to enhance the process of new material delivery to the student population, to provide a communication portal among the participants in the learning practice, and guide the students from a simple perception of information to expert evaluation and performance. To obtain a knowledge base for the academic progression, according to Bloom's classification of learning, students are required to read the textbook and attend the classes for lectures and educational activities.

The projector, one of the oldest representatives of the technology evolution in the educational sector, delivers visual aid to knowledge acquisition displaying images, video files, graphs, etc. on the wall screen. This technological device also assists educators in structuring the lecture flow and implanting a variety of features into classroom activities, which make this otherwise boring type of education more delightful and, therefore, more engaging for students in the learning environment and increases their motivation. Another valuable characteristic of a projector is its ability to unite all students into a mutual process of learning, not only by displaying the information but also by accommodating another technological tool-clickers.

Another common name for clickers is a personal response system. Clicker-based systems have recently been utilized in the health science programs, challenging students to answer several multiple-choice questions after a lecture. Students vote on a right answer by pressing a button on a clicker, and the results are displayed as a graph, demonstrating a percentage of participants who chose each available answer on a screen, thereby providing an immediate assessment tool. Some learners are easily involved in the instructor-student interactions in the classroom environment, while others feel intimidated or not comfortable being placed on the spot. Clickers eliminate this problem and invite students into the active discussion revolved around a current assignment. As a result, this technological approach to the learning process improves academic performance. A three-year study conducted at the University of California demonstrated that "the clicker treatment produced a gain of approximately 1/3 of a grade point over the no-clicker and control groups, which did not differ significantly from each other" [30].

Discussions do not have to happen inside the classroom. Communication technology adapted by many educational institutions, including Finlandia University, plays the role of social media and provides the opportunity to students to be engaged in the interpersonal dialog utilizing a virtual environment. Online and blended educational systems allow learners to participate in course activities at convenient times and locations. This approach accommodates the type of students, who have additional responsibilities outside of school; at the same time, it requires discipline and makes all students responsible for the learning process. The Finlandia University faculty utilizes eCollege to connect the course participants in one virtual environment by assigning reading material and discussion questions that lead the students through the cognitive stages of development. Students are required to provide personal experience to support their answers. This prerequisite stimulates emotional responses and encourages learners to explore and memorize the new information.

For students to complete the learning cycle and reach the desired proficiency, the educational program should consider the psychomotor aspect of Bloom's Taxonomy. Once again, the technology evolution assisted the Finlandia programs in this endeavor. Previously, nursing students had to experience an abrupt transition from theoretical knowledge to the practice of skills in hospital settings. Usually, hospitals can offer only a limited number of patients needing certain procedures. This situation created discomfort, dissatisfaction, and a stressful environment among students. Finlanidia University solved this problem by offering simulation as an educational method for the psychomotor and critical skill development of learners. According to Swenty and Eggleston [31], simulations are different in terms of fidelity—role playing and case scenarios represent a low-level simulation, progressing to the practice in laboratory settings; lifelike interaction with a manikin is a high-level simulation. The Finlandia University faculty has been implementing case studies and role-playing scenarios in online and classroom environments. Nowadays, the nursing faculty advanced the students' experience by providing interactive activities with a manikin. This approach mimics the clinical setting and allow students to overcome the discomfort during skill performance and practice the skill as many times as needed. Specifically, the nursing faculty utilizes a medium-fidelity manikin, Noelle, which simulates the birthing experience. This close-to-real-life medical case stimulates students to apply critical-thinking skills to the clinical situation being presented.

Mutual Aspects of Technology Utilization

Implementation of clickers by both educational institutions helps to engage students in the course activities, reflecting on research findings related to learning outcome improvement. This technological invention allows learners to collaborate in achievement of the task, expose them to the opportunity to analyze the previously acquired information, critically evaluate the present situation, and make a personal decision advancing them in the cognitive domain of the learning process. The personal response system also engages the wide diversity of students, despite the age, background, life experiences, or individual characteristic differences. Virtual environments supported by learning management systems, such as eCollege or Canvas, accommodate the students' preference for a blended model of education by providing flexibility in the learning process. In addition, online discussions cultivate a creative atmosphere for the students' communication and prompt them to work together on course material analysis and evaluation. These fundamental features optimize learning for adults and "net generation" students, leading them through Bloom's Taxonomy of learning.

Conclusions

Despite presenting differences in educational fields, technology utilization serves a mutual purpose for student advancement in the learning process by providing the communication system and accommodating educational progression based on Bloom's theory. Engineering and health-related programs at Michigan Technological University and Finlandia University demonstrated the similarities and varieties of technological tools utilized in student education. These tools allow educators to expand the scope of educational methodologies and conquer the evolving challenges of student diversity and differentiation of learning needs. Bloom's Taxonomy of learning, from the time of its foundation, has always provided educators with an authentic structure and guiding tool for the effective learning process. The current pace of technological advancement, on the other hand, impels educators wishing to provide the best educational practices to students to constantly update their technological skillsets.

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LIVE LONG AND PROSPER: A ROBOTICS-BASED RECRUITMENT AND RETENTION PROGRAM

Terry Marbut, Jacksonville State University; Jess Godbey, Jacksonville State University; Dana Ingalsbe, Jacksonville State University; Kelly Ryan, Robotics Education and Competition Foundation

Abstract

Increasing student enrollment and retention are issues given considerable importance in most institutions of higher education and are issues that many applied engineering or engineering technology programs grapple with on a continuing basis. With a myriad of potential strategies and limited available resources, finding solutions that produce documentable results can be daunting. One of the challenges associated with student enrollment in engineering-related programs lies in the limited number of P-12 students that develop interest in pursuing such careers. Challenges often associated with retention are the supposed large number of college students that are underprepared for engineering-related courses and the lack of project-based learning for students early in their college careers. In this study, the authors explored a comprehensive, robotics-based program that would attempt to address these challenges by integrating multiple initiatives at the P-12 and undergraduate levels. The program included teacher training and support for robotics education in P-12 systems. College students engaged in service learning activities and robotic design for competition. The program aspired to enhance both recruitment and retention of qualified students for engineering-related undergraduate programs. In this paper, the authors review the development and implementation of the program and discuss early results (both evidentiary and perceived).

Introduction

The literature describes several strategies that have been employed in efforts to increase the number of P-12 students interested in engineering-related careers. Participation in school-based activities is often suggested as a method to increase participation. Feldman and Matjasko [1] completed an extensive review of contemporary literature and concluded that participation in school-based extracurricular activities has many positive influences on the development and outcomes of adolescent and young adults. DeJarnette [2] concluded that providing early exposure to science, technology, engineering, and math (STEM) initiatives will improve recruitment. Another strategy described in a 2011 publication by Dischino et al. [3] encouraged project-based learning (PBL) by providing professional development for in-service teachers and creating a model course in PBL methodology for pre-service middle and high school teachers. Rhoads et al. [4] provided a model for after-school science clubs, based on university and K-5 partnerships. Another strategy by Michaeli et al. [5] provided a review of published literature regarding the use of robotics in schools. Their study was aimed towards determining how, for girls, robotics education may be used to positively influence their knowledge, interests, self -efficacy, and attitudes related to careers in engineering, and provided much data that confirmed the validity of such initiatives in general. Heaverlo [6] provided evidence that extracurricular STEM activities are significant in increasing the confidence and interest in math and science for female students.

Two challenges often associated with retention are the estimated large number of college students that are underprepared for engineering-related courses and the lack of project-based learning for students early in their college careers. Nationally, P-12 schools are implementing more engineering-related opportunities for students in response to the growing need for highly trained individuals in STEM fields, In spite of this, the percentage of students exposed to engineering-related classes and activities is still very small. Barker et al. [7] examined the impact of service learning on the engagement of Hispanic students in computing and STEM subjects, and the result was an increase in both recruitment and retention of students in STEM courses. In a 2012 white paper publication [8], the American Society for Engineering Education related best practices and strategies for retaining students in engineering-related fields. Service-based learning opportunities ranked as one of the best practices for increasing retention.

The establishment of a robotics team by an applied engineering department at a regional university provided the impetus for the development of a comprehensive robotics-based P-12 education program that was explored in this study. The robotics-based strategy for recruitment and retention is, in reality, a positive consequence of initiating a robotics team for undergraduate students. The Association for Technology, Management, and Applied Engineering (ATMAE) hosts a robotics competition at its national conference each year and the current authors' institution, JSU, made the decision in 2010 to establish a robotics club with the intention of competing annually at the ATMAE conference. The club performed well and has placed first in the national competition in two of the past five years. The excitement surrounding the initial activities (and success) of the robotics club led the department to develop a much broader plan that continues to have a positive impact on recruitment and retention. The current program encompasses P-12 teacher STEM training, based on a robotics-based curriculum, and ongoing support for competitive robotics programs in P-12 schools. These activities serve to increase the number of P-12 students that might consider engineering-related careers in general, and, specifically, the applied engineering programs at JSU. The service-based learning associated with support of the robotics competitions increases the engagement of the college students to aid in retention.

Teacher Training

The Department of Applied Engineering was able to partner with the JSU Inservice Education Center to develop a program to provide a one-week robotics training program for individuals teaching grades 3-12. The emergence of a Math and Science Partnership (MSP) grant provided the financing needed to support the partnership. The Inservice Education Center was already engaged in extensive math-based training for teachers that needed to be expanded, and the addition of robotics training provided much needed engineering based instruction.

A major decision in developing the training was determining what type of robotics platform to use. Nationally, there are several robotics programs available for use in P-12 schools. Included among the well-known programs are: Boosting Engineering Science and Technology (BEST) Robotics, For Inspiration and Recognition of Science and Technology (FIRST), and VEX. After extensive review of each of these outstanding programs, the decision was made to base training on the VEX program. The rationale for the decision was based on several factors that made the VEX program attractive to the intended purpose of the training. VEX has more teams competing than any of the other programs; provides a free curriculum for teachers that is cross-referenced to national science standards; can be integrated into a year-long curriculum; and provides standardized components that make the engineering design process less intimidating to teachers not having engineering backgrounds. Hendricks et al. [9] provided results from a survey of 341 students and 345 coaches, which revealed that "94% of coaches reported increased interest in science and technology and 50% reported increased interest in math and science classes," as a result of VEX robotics-based competitions.

The actual training program, targeting at adult learners, was developed in order to provide maximum interaction for participating teachers. Teachers started on Day 1 by building a basic robot system and finishing the week by participating in a mock tournament that simulated the experience that their students might encounter. After training, teachers were allowed continuing access to development software housed at the university, and could request technical assistance from the Department of Applied Engineering to support their efforts in the classroom. Teachers were provided with robotics kits that were used by the teachers during the training program. These kits could then be loaned to the teachers for use in their classrooms.

Over a three-year period, a total of 180 K-12 teachers received training. Elementary and middle school teachers utilized the VEX IQ platform and curriculum for training while, high school teachers and most middle school teachers used the VEX VRC platform. The number of teams participating in the state for the 2013-2014 academic year were 62 VEX VRC and 10 VEX IQ; for the 2014-2015 academic year were 101 VEX VRC and 39VEX IQ; and for the 2015-2016 academic year were 132 VEX VRC and 81 VEX IQ. This exponential growth represents a 213% increase in VEX VRC and an 810% increase in VEX IQ. This phenomenal growth has allowed over 22,500 Alabama K-12 students to be exposed to a high-quality STEM curriculum delivered by well-prepared teachers.

Service Learning and Retention

The remarkable growth of VEX robotics in the state has allowed students enrolled in the applied engineering programs to become more and more invested in service-based learning, as some students provide assistance to P-12 teams working on their robot designs, while others provide operational expertise for schools hosting state qualifying tournaments. The department hosts the State VEX Robotics Championships each year, providing yet another opportunity for actively engaging JSU students in relevant service learning. The students' high level of interaction with VEX robotics has earned them recognition within the organization, and each year a group of students is selected to serve during the VEX World Championships that include more than 1000 teams from more than 30 countries. Members of the robotics team also become involved with fund raising projects and public speaking opportunities.

The high level of engagement experienced by members of the robotics team seems to have positively impacted retention. In the five years that the team has been active, every team member has either graduated and is gainfully employed, transferred as planned to a traditional engineering program at another institution, or is still actively enrolled as a student in one of the programs offered at the institution.

The retention rate for the university is significantly lower with 72% of students persisting past the freshman year and only 33% reaching graduation. While conceding that students willing to become involved in extracurricular activities are to some extent more likely to persist than the general university population, and that other factors may also contribute to the significantly higher retention rate, it can be argued that at least some of the difference is attributable to participation in the program.

Recruitment

An additional benefit to these service learning activities is the accessibility that is afforded for recruitment. Students participating on VEX robotics teams are likely to be interested in some type of STEM-related career and, as JSU has a visible presence at events all through the school year, these students learn about the university's robotics team and the applied engineering programs. Hosting the state championships affords the students from the best teams in the state an opportunity to visit our campus and become more familiar with the facilities. There is extensive evidence that scholarship programs are very effective in recruitment, and JSU has designated a scholarship program for students that meet specific ACT/SAT scores and have participated in robotics during high school. These scholarships are announced at all events.

Conclusions

Results of the teacher training have obviously increased opportunities for students to be engaged in engineering-related activities, as indicated by the increase in the number of VEX teams registered in the state. Figure 1 shows this increase.

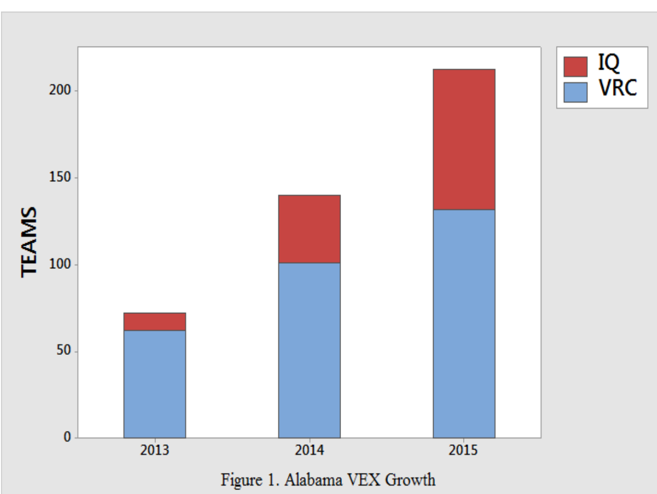

Figure 1. Alabama VEX Growth

The increased retention of students involved in the program relative to the general university population is considered significant, since previous research shows that retaining students is less costly than recruiting new students [10]. Finally, the growth of the robotics team over the past five years indicates that students recognize the benefits of program participation. Figure 2 shows this growth.

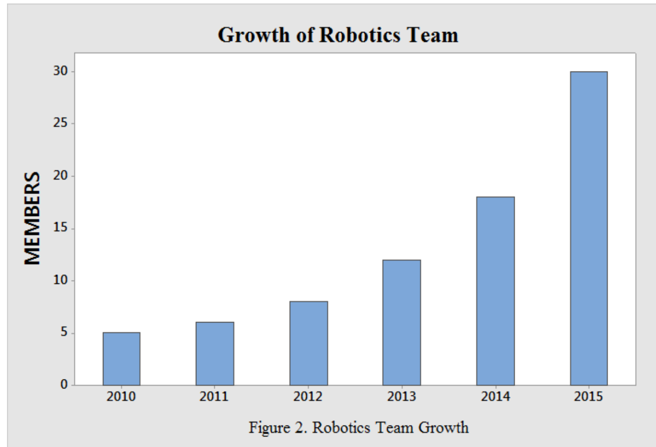

Figure 2. Robotics Team Growth

Data for impact on enrollment are not yet available, although there is informal evidence (increased phone calls, emails, etc.) that suggests that the program is causing high school students involved in the VEX program to consider the applied engineering programs. A longitudinal study will be required to determine the effect (if any) of participation in VEX robotics as a primary factor in subsequent enrollment in engineering-related programs in Alabama, as many of the students will not be making college decisions for several years. Overall, initial results look promising and are sufficient to warrant continuation of the program.

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Biographies

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UNDERSTANDING THE PHYSICS OF WATER ROCKETS USING WIRELESS SENSORS

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Abstract

Water rocketry is inherently a hands-on activity. Its practical nature has the advantage of engaging students, thus encouraging undergraduate students to explore and learn general physics concepts. Concepts from physics, statics, and fluid dynamics are needed to develop a system of ordinary differential equations that describe the motion of the rocket. Theoretical predictions are obtained by numerically solving the rocket's equations of motion using Euler's forward difference method. For this particular study, water rockets were fabricated using 2L soda bottles to investigate the effect of varied fin configuration on kinematic performance, with minimal changes in size and mass. Data were obtained from a wireless sensor that included an altimeter and a 3-axis accelerometer to measure vibration. Data analysis was performed to identify and explain probable causes of the differences. Results showed that the 3-fin rocket was within -6% of the predicted maximum altitude, in comparison to -10% for the 4-fin rocket under the same test conditions. In addition, the 3-fin rocket exhibited controlled flight characteristics, as reflected by its lower magnitude and shorter period of its damped oscillatory behavior in comparison to the 4-fin rocket. Students applied Newton's second law, analyzed associated free-body diagrams, and utilized concept of moments to further explain the differences in flight performance.

Introduction

Water rocketry is a practical and fun activity that can be utilized in a variety of undergraduate courses, including physics, fluid dynamics, and engineering measurements. The engaging nature of this approach helps students gain an appreciation for Newtonian physics, statics, and fluid dynamics. While a popular activity among K-12 students, there appear to be only a handful of publications pertaining to water rocketry with theoretical treatment targeting undergraduate [1-4] and graduate [5-7] students. In these studies, flight data were acquired either using expensive high-speed cameras [8], older electronic methods [9], or a mathematical triangulation approach [5] to measure altitude. In addition, analyses were limited to the initial thrust phase during water/air expulsion, maximum altitude, and distance traveled.

Advances in data acquisition, both in accuracy and cost, allow this current study to add to the existing knowledge base by acquiring altitude and vibration data for the entire flight with a cost-effective and simple-to-use wireless sensor to explain flight performance. Furthermore, equations of motion for a water rocket were derived; a numerical solution to the theory is presented here. Directional stability of rockets is also examined. Experimental results of two rocket designs were compiled and compared to theoretical prediction of altitude; a discussion of the probable cause of the differences in flight performance are also presented here.

Newton's Second Law

Kinetics of a water rocket can be investigated by analyzing the forces that affect rocket motion, which include forces due to aerodynamic drag, gravity, and thrust from water being expelled. Newton's second law, Bernoulli's principle, and adiabatic expansion of air concepts are used to develop the equations of motion of a water rocket. As water is expelled from a water rocket, the thrust force it generates is given by Equation (1):

$$F_{Thrust} = u_{exit} \frac{dM_{\exp w}}{dt} \tag{1}$$

where, u_{exit} is the velocity of the water at exit relative to the rocket and $dM_{exp\,w}/dt$ is the mass flow rate of the expelled water.

The gravitational force is given by Equation (2):

$$F_{Gravity} = M_R g \tag{2}$$

where, M_R is equal to the mass of the rocket (including water) and a function of time, and g is the gravitational constant.

The aerodynamic drag of the rocket is given by Equation (3):

$$F_{Drag} = \frac{1}{2}\rho_{air} C_D A |v_R| v_R \tag{3}$$

where, the density of air is ρ_{air}; C_D is the drag coefficient; and A is the frontal area.

The velocity v_R and the absolute value of the velocity $|v_R|$ are necessary to account for the sign change of the velocity during descent.

An expression of the acceleration of the rocket can be obtained by substitution of these three equations into Newton's second law, shown in Equation (4):

$$a_R = \frac{\sum F}{M_R} = \frac{F_{Thrust} - F_{Gravity} - F_{Drag}}{M_R} \tag{4}$$

Bernoulli's Law and Adiabatic Assumption

To derive a numerical solution to predict the kinematics of a water rocket, it is necessary to express F_{Thrust} from Equation (4) in terms of air pressure inside the bottle. The initial value of this controlled variable was used as a starting point for the numerical solution. To accomplish this, the mass flow rate of water term $dM_{exp\,w}/dt$ in Equation (1), which is equivalent to the volumetric flow rate, can be expressed by Equation (5):

$$\frac{dM_{\exp w}}{dt} = \rho_w \frac{dV}{dt} = \rho_w A_{exit} u_{exit} \tag{5}$$

where, ρ_w is the density of the water; $dV\ /\ dt$ is the volumetric flow rate; and A_{exit} is the cross-sectional area across which the water is expelled.

Next, u_{exit} is expressed as a function of air pressure by using Bernoulli's principle, given by Equation (6):

$$P_{air,1} + \frac{1}{2}\rho_{w,1}v_1^2 + \rho g h_1 = P_{air,2} + \frac{1}{2}\rho_{w,2}v_2^2 + \rho_{w,2} g h_2 \tag{6}$$

where, location 1 is considered to be at the water and air interface inside the bottle and location 2 is at the exit (see Figure 1); variables P, ρ, v, and h are internal air pressure, density of water, velocity of water, and height of water, respectively, at locations 1 and 2.

Bernoulli's equation is simplified by approximating of $\rho g h_1 \approx \rho g h_2$ and $v_1 << v_2$. In addition, when changes in notations are made, where $P_{air,1} = P_{air\ inside}$, $P_{air,2} = P_{exit}$, and $v_2 = u_{exit}$, Bernoulli's principle to reduces to Equation (7):

$$u_{exit} = \sqrt{\frac{2\left(P_{air\ inside} - P_{exit}\right)}{\rho_w}} \tag{7}$$

An expression for term $dM_{exp\,w}/dt$ can be obtained by substituting Equation (7) into Equation (5). The resulting expression can then be substituted into Equation (1) to yield F_{Thrust} as a function of pressure, as given by Equation (8):

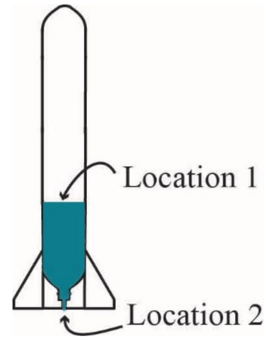


Figure 1. Locations 1 and 2, as Referenced in Bernoulli's Principle [Equation (6)]

$$F_{Thrust} = 2\left(P_{air\ inside} - P_{exit}\right) A_{exit} \tag{8}$$

Substitution of this new F_{Thrust} expression, gravitational force Equation (3), and aerodynamic drag force Equation (2) into Newton's second law Equation (4) yields Equation (9):

$$a_R = \frac{2\left(P_{air\ inside} - P_{exit}\right) A_{exit} - \frac{1}{2}\rho_{air} C_D A |v_R| v_R - M_R g}{M_R} \tag{9}$$

The changes in altitude y_R and velocity v_R of the rocket are respectively given by Equations (10) and (11):

$$dy_R = v_R dt \tag{10}$$

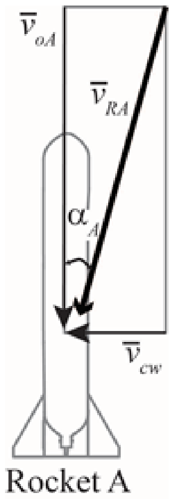
and

$$dv_R = a_R dt \tag{11}$$

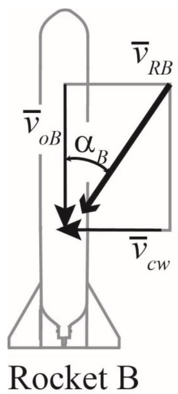
Equations (9)-(11) are the kinematic equations that describe the motion of the water rocket and numerical solutions can be obtained using Euler's method of forward time differentiation using $\Delta t = 0.001$s time steps [10, 11].

Weather Vaning

At launch, rockets have a tendency to rotate about their center of gravity, Cg, in the presence of crosswinds. Consider rockets A and B (see Figure 2), which are launched with initial speeds of v_{oA} and v_{oB} , respectively. Allow the velocities of the air moving over the rockets to be $\overline{v}_{oA}$ and $\overline{v}_{oB}$. If each rocket is subjected to crosswind $\overline{v}_{cw}$, then by vector addition, the resultant vectors $\overline{v}_{RA}$ and $\overline{v}_{RB}$ act at angles about the y-axis of each rocket as shown. Figure 2 shows how this causes each rocket to rotate to an angle of attack, a , with $a_A < a_B$, due to the fact that $\overline{v}_{oA} > \overline{v}_{oB}$. This rotation is also known as weather vaning, and ultimately affects the directional stability of the rocket.



(a) Large Magnitude of Initial Velocity $\overline{v}_{oA}$ Results in a Smaller Angle of Attack α_A



(b) Small Magnitude of Initial $\overline{v}_{oB}$ Results in a Larger Angle of Attack α_A

Figure 2. Initial Rocket Velocity and Crosswind Velocity Affect the Degree at Which the Rocket Will Turn (or weather vane) into the Wind at Angle of Attack α

Static Directional Stability

If the rocket is designed to be stable then the angle of attack will minimize through a series of oscillations that eventually dampen [12]. The degree of the oscillations is a function of the magnitude and locations of two net forces, $F_{net\,Cg}$ and $F_{net\,Cp}$ (see Figure 3), which act at the center of gravity (⊕) and the center of pressure (⊙), respectively. The net force $F_{net\,Cg}$ is the sum of $F_{Gravity}$, F_{Drag}, and F_{Thrust} and affects translation. $F_{net\,Cp}$ is the net pressure force due to air pressure field about the body of the rocket and affects rotation. When no crosswind exists [see Figure 3(b)], the force resulting from the net pressure is zero, and the rocket assumes an ideal vertical trajectory.

Figure 3(c) shows a more realistic case, where, in the presence of crosswind, the net pressure force $F_{net\,Cp}$ generates a moment about *Cg* (⊕). Figure 3(d) shows how the rocket rotates counterclockwise to an angle of attack of $-\alpha$. For a stable rocket, it will go through a series of oscillations in the pitch/yaw directions and eventually dampen. Figure 3 (e) shows how an undesirable situation arises when *Cp* (⊙) is ahead of *Cg* (⊕). The moment created by the net pressure force $F_{net\,Cp}$ about *Cg* causes the rocket to rotate clockwise. This can result in an increase in an angle of attack that is too large for the forces to minimize α, and can cause the rocket to assume an erratic/unstable flight pattern. Thus, directional stability is affected by the magnitude of the net pressure force $F_{net\,Cp}$ and its moment arm (i.e., the distance between *Cp* and *Cg*).

Net Pressure Force

A method for mathematically locating the center of pressure distance $\overline{Y}_{Cp}$ of a subsonic rocket was first presented by Barrowman [13, 14], with the following assumptions:

- Flying at low α
- Axisymmetric and rigid body
- Steady and non-rotational flow around the body
- Nose with a sharp point
- Fins modeled as flat plates

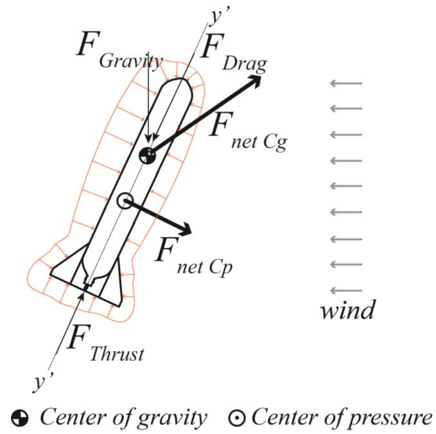
Barrowman's equations can be modified to express $\overline{Y}_{Cp}$ as a function of α [15, 16]. The modified Barrowman's equations to determine $\overline{Y}_{Cp}(\alpha)$ are repeated here for convenience and will be used to understand the static directional stability of the rocket in the discussion section.

Dividing the rocket into three distinct sections—nose, body, and fins—the net pressure force N_i that acts at the centroid $\overline{y}_i$ [see Figure 4(a)] of each section is given by Equation (12):

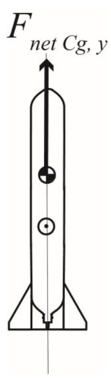
$$N_i = (C_{N\alpha})_i \frac{1}{2} \rho_{air} v^2 \alpha A_{rR} \tag{12}$$

where, v is the velocity of air moving over the rocket; α is the angle of attack in radians; and A_r is the cross-sectional area of the rocket's body. The parenthetical term $(C_{N\alpha})_i$ is called the shape coefficient and directly affects the magnitude of N_i. The location of the rocket's *Cp* can be determined by summing the moment of each N_i about the nose tip and equating it to the total moment of the rocket, as given by Equation (13):

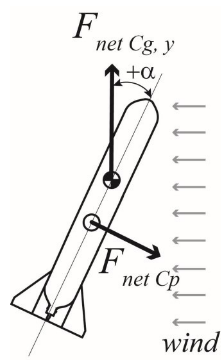
$$\sum N_i \overline{y}_i = \sum (C_{N\alpha})_i \overline{Y}_{Cp} \tag{13}$$



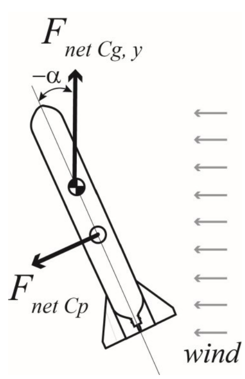
(a) Free-Body Diagram of a Rocket during Flight



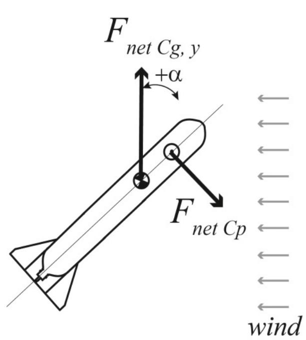
(b) Free-Body Diagram of an Ideal (no cross wind) Rocket Launch



(c) The Rocket Rotates about Its Cg (⊕) Due to $F_{net\ Cp}$

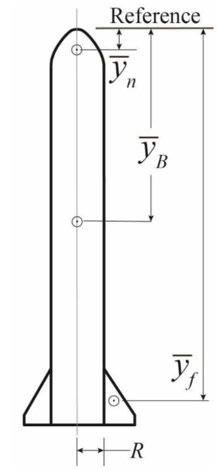


(d) The Rocket Rotates Counterclockwise to an Angle of Attack of -α

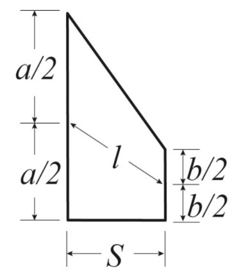


(e) When Cp (⊙) is Ahead of Cg (⊕), It Causes the Rocket to be Unstable and Rotate Clockwise

Figure 3. Static Directional Stability of the Rocket is a Function of the Locations of the Net Forces at the Center of Gravity $F_{net\ Cg}$ and Center of Pressure $F_{net\ Cp}$



(a) Geometry of the Rocket and Centroids of the Nose, Body, and Fins



(b) Geometry of the Fin

Figure 4. Geometry of the Rocket Showing the Centroids of the Nose, Body, and Fin $\bar{y}_n$, $\bar{y}_B$, and $\bar{y}_f$, Respectively

Solving Equation (13) for $\bar{Y}_{Cp}$ yields Equation (14):

$$\bar{Y}_{Cp} = \frac{\sum N_i \bar{y}_i}{\sum (C_{N\alpha})_i} \tag{14}$$

The expressions for the shape coefficients for the nose (n), body (B), and fin in the presence of the body (fB) are defined respectively by Equations (15)-(17) [13, 16]:

$$\left(C_{N\alpha}\right)_n = 2\alpha \quad \text{(conical or parabolic nose)} \tag{15}$$

$$\left(C_{N\alpha}\right)_B = \frac{KA_B}{A_{ref}}\alpha^2 \tag{16}$$

$$\left(C_{N\alpha}\right)_{fB} = \left(1 + \frac{R}{R+S}\right) \frac{4n\left(\frac{S}{2R}\right)^2}{1 + \sqrt{1 + \left(\frac{2l}{a+b}\right)^2}}\alpha. \tag{17}$$

Figure 4(b) shows how the variables a, b, l, R, and S are related to the geometry of the fin. Substitution of Equations (15)-(17) into Equation (14) yields the desired location of the center of pressure $\overline{Y}_{Cp}$ as a function of α.

Fabrication of the Water Rocket

Figure 5 depicts a water rocket fabricated using 2L soda bottles. The cavity just below the nosecone housed the wireless sensor in protective foam, and a recovery parachute. The body was lengthened using another bottle that was attached to the main chamber with epoxy. Interchangeable fin assemblies with three and four fins were made using 3.175 mm thick corrugated plastic. The length of the nosecone was 110 mm and the body was 553 mm in length with R = 55.7 mm. Figure 4(b) shows the dimensions a, b, l, and S to be 140, 35, 78, and 70 mm, respectively.

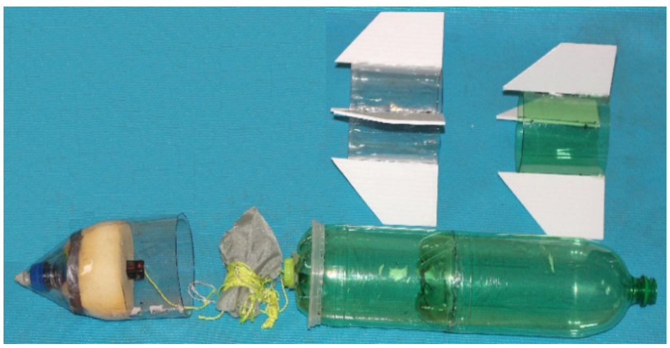


Figure 5. Water Rocket Fabricated Using 2L Soda Bottles

The rocket launcher was made using various 12.7 mm diameter brass pipe fittings (see Figure). It was equipped with a pressure gage, pressure relief value, check valve to control the direction of air flow, and an adapter for connection to an air compressor or bicycle pump.

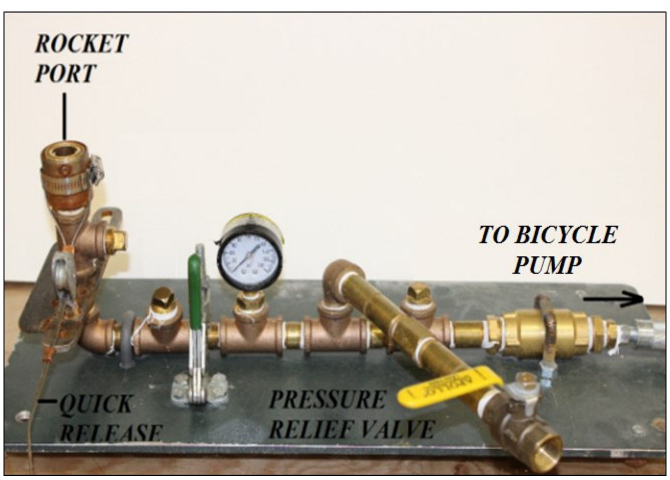


Figure 6. Water Rocket Launcher

A standalone wireless Bluetooth sensor [17] equipped with an on-board data acquisition system was used to measure altitude at a rate of 20 Hz and acceleration about three axes at a rate of 200 Hz. The size of the sensor measured 49mm x 18mm x 14.5mm and could be recharged using a USB cord. The total mass of the sensor and batteries was 10.5 g. The manufacturer's application installed on a smart device (smartphone and iPad) was used to view a graphical plot of the flight data immediately after each flight, as well as transmitting a CSV spreadsheet file wirelessly to an email account and/or to cloud storage for later analysis.

Results and Discussion

Physical Properties and Flight Conditions

Rockets were launched to an elevation of 696m. The temperature was approximately 15.6°C with an average crosswind of 3.5 m/s [18]. The 2L bottle that housed the water had a total volume (V_{bottle}) of 0.0028m^3, body diameter d_{bottle} of 111.5 mm, and water discharge area A_{exit} of 113 mm^2. The main chamber was filled with 0.8L of water and pressurized between 30-70 psi for all flights. Table 1 shows the physical properties of the rocket: air and water.

Table 1. Physical Values for Air, Water, and Atmospheric Conditions

	$\overline{Y}_{Cp}$ mm	$\overline{Y}_{Cg}$ mm	M_R (g)	ρ_{air} kg/m^3	ρ_w kg/m^3	P_{exit} kPa
3-fin	400	295	238	1.225	1000	101
4-fin	411	300	246			

Flight Performance

Visual observations indicated that all rockets flew vertically upward and then arced on descent. Erratic flight patterns were not visually observable for any flight. Figure 7 shows typical outputs from the sensor, consisting of altitude and total acceleration, for a 3-fin rocket launched using 60 psi. Several distinct phases included pressurization, water and air expulsion, damped oscillations, and descent. As the pressurized air rushes into the main chamber, the rocket vibrates. At takeoff, the expulsion of water creates an impulse that reaches a peak acceleration of 6.6g's. After the water is completely expelled, acceleration decreases suddenly to 4.1g's. The acceleration subsequently increases to 5.7g's, due to the expulsion of the compressed air and the loss of mass from the expelled water. At 0.7s, with no remaining water or compressed air, the rocket is in free-flight. At this stage, damped oscillations are observed, indicating pitch and yaw motions of the rocket as it attempts to overcome the effects of weather vaning. When oscillations have completely dampened, the rocket reaches its apogee of 23.2m. During descent, the nosecone separates from the body. Oscillations of 2.5s< *t* < 5.1s reflect the nosecone swinging like a pendulum from the parachute as the assembly descends. A sudden spike was seen at 5.3s, as the nosecone impacted the ground with a total acceleration of 10.2g's.

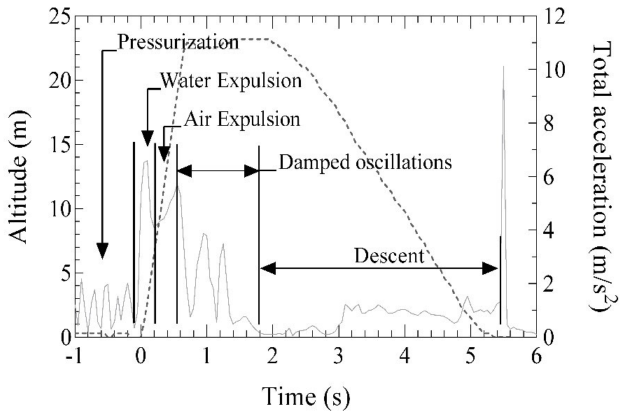
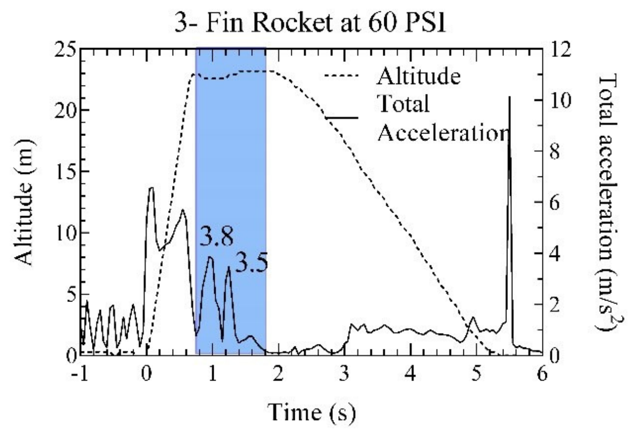


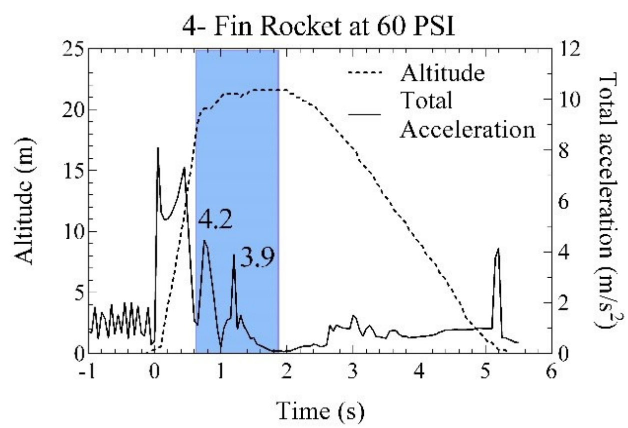
Figure 7. Three-Fin Rocket Pressurized to 60 psi Using an Initial Water Volume of 0.8L

The effect of fin configuration on flight performance was analyzed by collecting data for two fin configurations, while keeping all other variables constant. Figure 8 shows flight data from a 3-fin and 4-fin rockets using the same volume of water of 0.8L at 60 psi. Since there was a difference of only eight grams between the 3-fin and 4-fin rockets, the numerical predictions for the maximum height were 24.6m and 24.0m, respectively. These values represent errors of -6% and -10% for the 3-fin and 4-fin rockets, respectively. Damped oscillations of each phase were compared (shaded region in Figure 8) to examine why the performance of the 3-fin rocket was better. Both rockets exhibited two distinct peaks in the total acceleration trace. However, the magnitudes of these peaks for the 3-fin rocket were lower (3.8 and 3.5g's) and slightly shorter in duration than the 4-fin rocket (4.2 and 3.9g's). This could imply that the 3-fin rocket experienced smaller pitch/yaw motions, thereby indicating a better controlled flight pattern, resulting in a higher altitude. Differences in maximum altitude and magnitudes of the total acceleration during the damped oscillatory phase (shaded region) is noticeable.

The pitch and yaw motions of the rocket are largely influenced by the magnitude of the net pressure force and the moment it creates about *Cg*. Using Equation (17), the fin shape coefficients of the 3-fin and 4-fin rockets were calculated to be 3.1m and 4.1m, respectively. This corresponds to a 25% greater net pressure force for the 4-fin rocket. The implication of this larger force is the larger moment it creates about *Cg* , causing the 4-fin rocket to experience larger oscillations in the angle of attack. The end result may have been a flight trajectory that prematurely arced, resulting in a lower altitude than predicted.



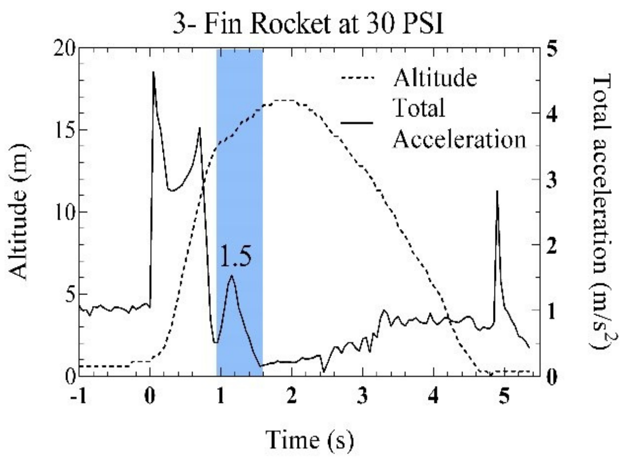
(a) 3-Fin Rocket at 60 psi



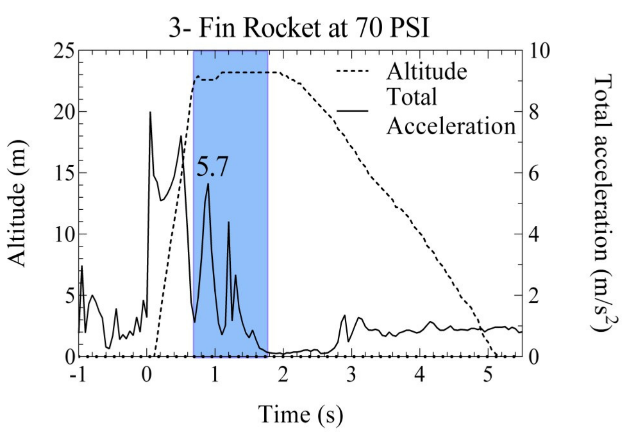
(b) 4-Fin Rocket at 60 psi

Figure 8. Altitude and Total Acceleration Data of 3-Fin and 4-Fin Rockets Launched Using 0.8L of Water at 60 psi

The wireless sensor was useful in comparing differences in flight stability for the 3-fin rocket flown at a low pressure of 30 psi and a high pressure of 70 psi (see Figure 9). The 30 psi flight exhibited less dramatic yaw/pitch accelerations during the damped oscillation phase (shaded region) in comparison to the 70 psi flight. The peak magnitudes of the total acceleration support this observation. Although both flights demonstrated damped oscillations, the low-pressure flight required only 0.6s to dampen half of a sinusoidal signal [see Figure 9(a)]. For the high-pressure flight, there were multiple oscillations and a total of approximately 1s was required to reach steady state. One possible explanation is that the lower initial velocity attained by the 30 psi flight caused the rocket to leave the launch pad at a larger angle of attack, due to weather vaning effects as discussed earlier. Due to its low speed, the net pressure force was probably insufficient to create a moment about *Cg* that could quickly decrease the large angle of attack it had sustained. This resulted in less dramatic pitch/yaw movements of the rocket, as indicated by the peak magnitude of the half sinusoidal cycle of 1.5g's at $t = 1.15$s. For the high-pressure flight, the higher initial velocity created a net pressure force sufficient to create a moment and quickly respond to its initial angle of attack, as evidenced by the multiple damped cycles with an initial peak 5.7g's at $t = 0.9$s.



(a) 30 psi



(b) 70 psi

Figure 9. Launch of the 3-Fin Rocket Using 0.8L of Water

Conclusions

Water rockets were fabricated from 2L soda bottles with 3- and 4-fin configurations. Rockets were launched using 0.8L of water at pressures ranging from 30-70 psi. A cost-effective wireless sensor was used to acquire altitude and acceleration flight data. The wireless sensor data indicated that the 3-fin rocket exhibited better static directional stability and resulted in a higher altitude in comparison to the 4-fin rocket under the same flight conditions. Concepts from undergraduate subjects such as dynamics, general physics, and fluid dynamics were used by students to explain the performance differences observed between the two rocket configurations.

The wireless sensor was fairly easy to use and provided opportunities for students to investigate stability of flight that would not have been possible without the sensor. While deficiencies in data acquisition are identified below, the sensor provided a practical, low-cost method of providing active learning opportunities to a large number of students. Furthermore, the use of a simple, low-cost device provided an opportunity for discussing the balance between economics and accuracy in real-world applications of problem solving.

Improvement to this exercise would be to address the low sampling rate of 20 Hz and large uncertainty of $\pm$ 0.25m of the altimeter portion of the sensor. This limitation resulted in observations of false artifacts such as the plateaus in Figure 7. In addition, the true total acceleration of the rocket could have been masked, due to the accelerometer's low sampling rate of 20 Hz. These issues could be resolved by using an altimeter with a higher sampling rate of 100 Hz and lower uncertainty of $\pm$ 0.1m, so that better correlation in altitude could be obtained. As for the accelerometer, a 400 Hz sampling rate would yield a resolution of 0.0025s and should be sufficient to capture the desired acceleration characteristics at launch.

Future studies will include monitoring the rocket's change in angle of attack during flight using an inertial measurement unit (IMU). An IMU sensor contains both an accelerometer and a gyroscope, which allows the angle of attack during flight to be determined. Integration of an IMU sensor can range from wireless units to hard-wiring individual IMU sensors to a micro-controller such as an Arduino. Another option would be to utilize the IMU sensor available in most modern smartphones along with an app to efficiently and cost-effectively acquire the necessary data to calculate altitude, vibration, and the angle of attack during rocket flight.

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Low-Cost Solutions for Wireless Communication Systems for Undergraduate Engineering Technology Students

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Abstract

Training engineering technology students requires hands-on projects in addition to simulation-based experimentation performed using software packages such as Matlab or LabVIEW. The emergence of low-cost platforms such as Raspberry Pi or Arduino enable the use of free open-source code for experimentation and provide flexibility, resulting in projects with low overall costs. In this paper, the authors discuss a number of applications of low-cost microprocessor platforms in the area of wireless communications. These include a transmitter-receiver system using Raspberry Pi and software-defined radio boards, along with a wireless sensor network with Arduino and Raspberry Pi processors. Additional applications include low-cost control systems using wireless-enabled devices, which students can program using the Bluetooth interface of their smartphones. These platforms allow students to experiment with visual programming block languages to program different types of mobile devices. Having opportunities to use low-cost, shared, and customizable hardware platforms, students can learn how to use various wireless technologies to create communication networks that integrate electrical and mechanical components as symbiotic parts of mechatronic (electromechanical) systems, and incorporate these designs into their capstone projects.

Introduction

The use of low-cost microcontrollers and single-board computers, such as Arduino and Raspberry Pi, has seen a significant increase in recent years, as demonstrated by the multitude of projects and education platforms based on them, as well as by the vast amount of articles discussing their use, which are briefly reviewed here. They are used in a wide range of applications by hobby groups and professionals, as well as by academic institutions, for both teaching and research projects. Aside from being affordable, an additional benefit is provided by the wide support available for their use through open source code libraries and online engineering communities and forums. This makes learning how to use microcontrollers a less-daunting endeavor for novice users [1]. Parallel between different options for teaching robotics with technology were considered, including Arduino and Raspberry Pi [2]. Raspberry Pi, Arduino, and BeagleBone Black processors were compared from an Internet of Things perspective [3], and the analysis favored Raspberry Pi as the best choice in terms of price, features, and performance.

A plethora of application examples is available in the literature, with different levels of complexity, and coming from a variety of areas such as environmental monitoring, biomedical applications, and interface devices. In the first category are solar energy-powered sensors, along with low-cost customizable devices that include an Arduino microcontroller and XBee communication modules [4-6]. Another example is a smart-city application in which a Raspberry Pi and a ZigBee sensor network were used to control street lighting [7]. Medical applications of low-cost hardware platforms include numerous projects that used Arduino microcontrollers and Zigbee sensors to build affordable wireless sensor networks for collecting data or controlling biomedical devices. An example in this direction was a low-cost retina-controlled device, consisting of a head mount and a wrist tilt designed to assist people affected by paralysis using a computer or a smartphone [8]. Another biomedical application consisted of a wireless sensor network for heart-rate monitoring in sports training [9], which used Arduino-Nano and XBee wireless modules to determine the intensity of a training session or race by measuring heart rate. In vision research, Arduino was used to generate a pulse-width modulation signal to control LEDs to provide linear light intensity control for light stimuli, an affordable application that offers flexibility for a wide range of research projects and for educational purposes [10].

Examples of applications for interfacing devices include the streaming of live video feeds from a microscope to a remote location at different resolutions that can be selected by the user [11], an integrated home appliance control [12], wireless networks for mobile robot applications [13], and data acquisition systems [14]. Low-cost microcontrollers, such as Arduino, have both digital and analog inputs/outputs (I/O), which make them ideal platforms for hosting multiple hybrid sensors for various physical quantities [1] as well as for controlling and coordinating actuators [4]. Additionally, Arduino and Raspberry Pi have been used to provide low-cost localization solutions in standalone applications [5, 15] or in conjunction with smartphones working with iOS or Android communication protocols [11].

Different academic programs have been introducing, in both lower- and upper-division classes, low-cost hardware platforms using Arduino microcontrollers and Raspberry Pi computers. The SparkFun Inventor's Kit, which contains an Arduino microcontroller, has been used in an undergraduate computer science program in a sequence of courses designed to teach students embedded systems design and microcontroller programming, enabling them to apply computer science knowledge to solve real problems [16]. The same computer science program also introduced Arduino-based projects in capstone design courses [17]. An Arduino board and a Raspberry Pi running REX Control System were used along with Simulink for teaching control classes [18]. Arduino-based platforms were also used to teach embedded systems and robotics [19] as well as wireless sensor network design [20], as part of an introductory course about circuits and systems. In this latter application, the Arduino was used in conjunction with Zigduino, an antenna-embedded microcontroller board that adds wireless capabilities, based on the IEEE 802.15.4 protocol. Both Arduino and Raspberry Pi can be used as teaching platforms for embedded systems and microcontroller programming courses, since they have the software/hardware co-design possibility [21, 22]. Raspberry Pi is also considered as a choice for teaching emerging technologies such as the Internet of Things [23].

Using Low-Cost Hardware Platforms in Electrical Engineering Technology Projects

In the Engineering Technology Department at Old Dominion University, students pursuing the Electrical Engineering Technology (EET) track are required to complete a hands-on capstone project that consists of designing, building, and demonstrating the operation of an electrical/electronic system. Recent projects used Arduino platforms along with sensors and XBee communication modules, which have become very affordable and for which a large library of open source software is available. As the community of Arduino users increases, Arduino-based projects are becoming increasingly intriguing for students, enabling them to showcase creative components in their designs. Technology students wanting to specialize in communication systems can do so by taking a sequence of two technical elective courses, which introduce them to the concepts of frequency analysis and teach them principles of analog and digital modulation. However, while other courses and laboratories have hands-on projects, in these courses, Matlab has been used for many years to study basic modulation/demodulation schemes through software simulations, and students had no opportunity to work on hands-on projects in the area of communication systems.

Recently, the Raspberry Pi platform was introduced in hands-on communication projects for EET students. An example in this direction is using Raspberry Pi and software defined radio (SDR) platforms to implement a low-cost versatile communication system consisting of a short-range radio transmitter with an associated receiver. An SDR consists of a field-programmable gate array (FPGA) core that works in conjunction with radio-frequency (RF) front-end modules and can act as transmitter/receiver for radio signal in various frequency bands. Programming, configuration, and experimentation with SDR platforms require connection with a host computer. The use of desktop computers is preferred for heavy programming and development of SDR libraries, while portable and embedded computers like the Raspberry Pi are favored for experimentation in indoor and outdoor setups.

Among the various SDR platforms available on the market, the Universal Software Radio Peripheral (USRP), developed by Ettus Research (a National Instruments company), has emerged as the leading choice for educational activities and academic projects [24], and was selected for this particular project. Specifically, two USRP1 boards, powered by an Altera Cyclone FPGA and featured with basic Tx/Rx daughterboards operating in the 1-250 MHz band, were used to set up a wireless link. A desktop computer was used to control the transmitter, while a Raspberry Pi was used for the receiver and the GNU radio companion open source software was used to program both of them. Figure 1 shows the block diagram of the communication system implemented in this current study. The desktop and Raspberry Pi computers can interchange their roles in the transmitter/receiver system, and the two Raspberry Pi computers can be used for added portability.

Using the GNU radio companion software, students can program the transmitter USRP to generate and transmit a sinusoidal waveform. This signal is received by the second USRP board, which processes it for display of the FFT of the received signal. Once the system has been proven to work with this simple signal, the next step is to perform experiments with more complex transmitted signals and different setups of the communication system. Different types of transmitted data as well as indoor/outdoor settings can be considered, and more complex experiments can be implemented that require more processing levels at both transmitter and receiver ends. Various modulation methods can be used, with modulation algorithms implemented on the Raspberry Pi computer and USPR boards, and their efficiency in specific environment settings can be tested.

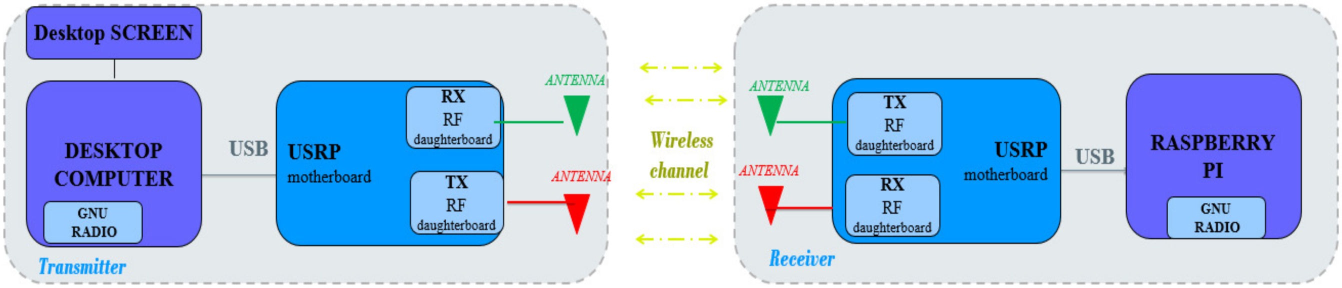

Figure 1. Block Diagram of a Raspberry Pi and SDR Communication System

Figures 2 and 3 present the receiver and the complete system, with the desktop computer and the antenna. This implementation can also be used for class demonstrations or hands-on experiments associated with communication courses, as different modulation algorithms can be implemented in software and used with the SDR boards.

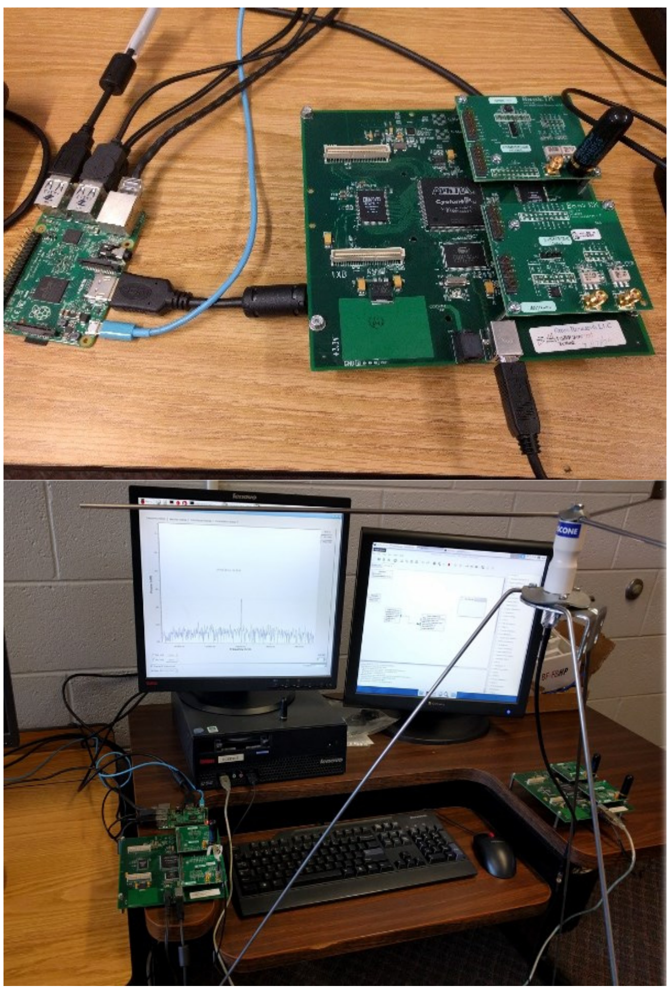

Figure 2. Raspberry Pi and SDR Receiver

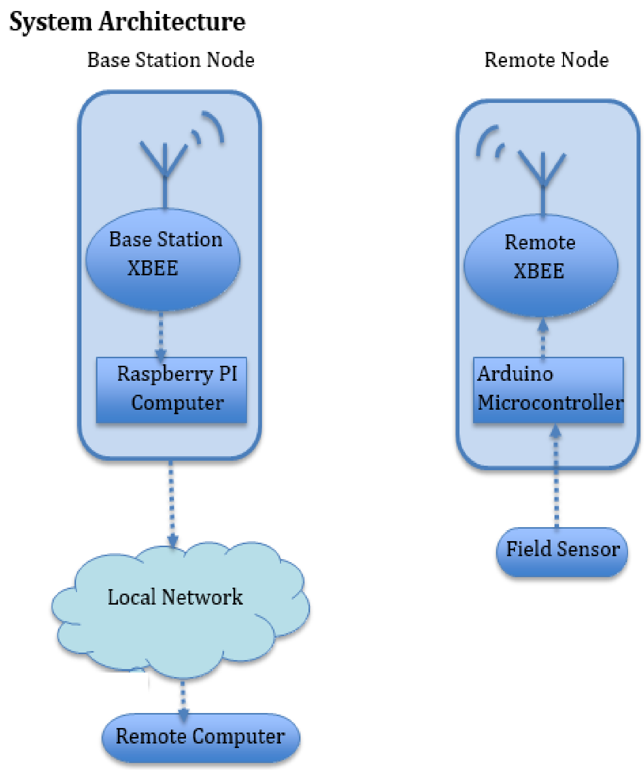

Figure 3. The SDR Communication System

A second undergraduate project included the implementation of a wireless sensor network using an Arduino microcontroller to interface a sensor and a Raspberry Pi computer in order to gather the sensor data. Potential uses for this sensor network are in the context of a manufacturing line to monitor parameters of individual stations, in medical rooms, or in the cockpit of an aircraft or unmanned autonomous vehicle, where the need for miniaturization naturally leads to wireless collection and transmission of sensor data, or for some small projects such as a wireless fire alarm that uses a temperature sensor in the design. Figure 4 shows the block diagram and the actual implementation of a wireless sensor data collection system.

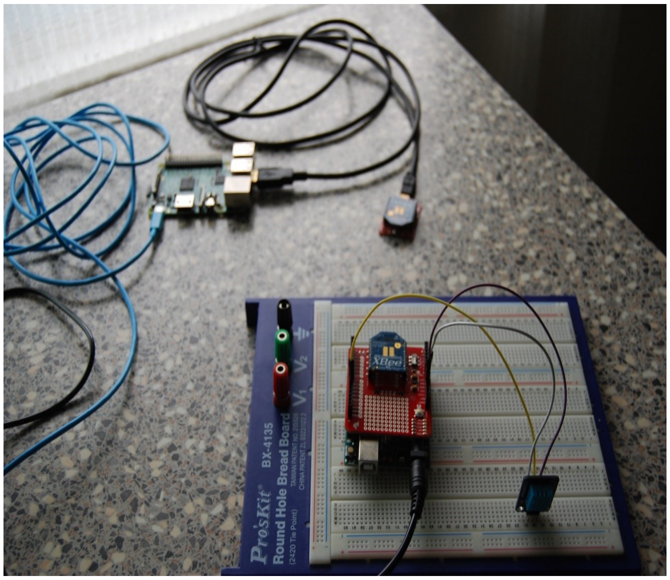

Figure 4. Wireless Sensor Network

The network implemented by the students for this project included a remote sensor (for temperature or humidity) from which data were collected using the Arduino microcontroller to wirelessly transmit the data to a Raspberry Pi computer. This was further connected to a local network over which the sensor data were transmitted to a remote computer for storage and processing. While Arduino and Raspberry Pi worked as main processors, the XBee ZigBee wireless transmitter/receiver modules were used as wireless radios.

Using Low-Cost Hardware Platforms Mechanical Engineering Technology Curricula

In the Mechanical Engineering Technology program at Old Dominion University, the SparkFun Inventor's Kit was used in the Introduction to Mechatronics course, where the students had to work on assignments requiring Arduino programming in online setup labs [25]. This course deals with the study of mechatronics concepts and their application to real problems encountered in engineering practice. It covers the basics of electromechanical systems, electrical circuits, solid-state devices, digital circuits, and motors, all of which are fundamental to the understanding of mechatronics systems. Some of the course objectives focus on electric circuits and components used in mechatronic systems, microcontroller programming and interfacing, and application of sensors and actuators in mechatronics. Figure 5 shows a SparkFun Inventor's Kit with an Arduino platform that was used in labs associated with this course for hands-on projects.

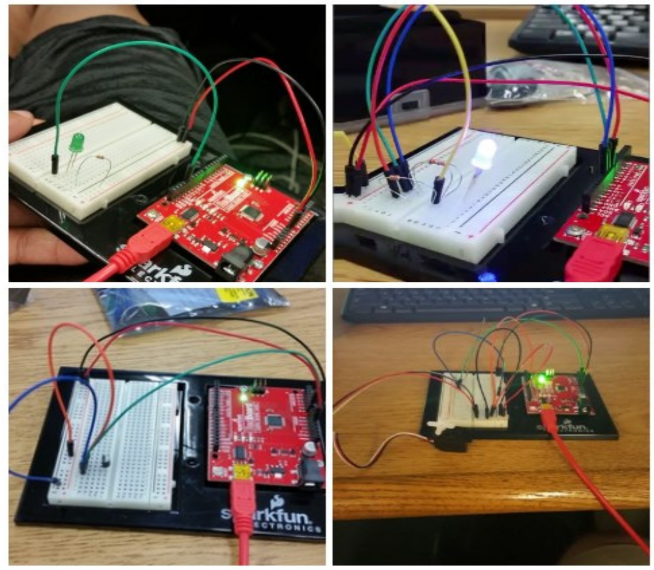

Figure 5. Example Labs based on a SparkFun Inventor's Kit with an Arduino Platform

One such project on which students worked during this course was suggested by the Department of Physics in the College of Science. Ultrasonic sensors controlled by Arduino processors were used in studio labs, where freshman students take physics courses, and a housing design for these sensors was needed. Figure 6 shows the housing design developed by the students.

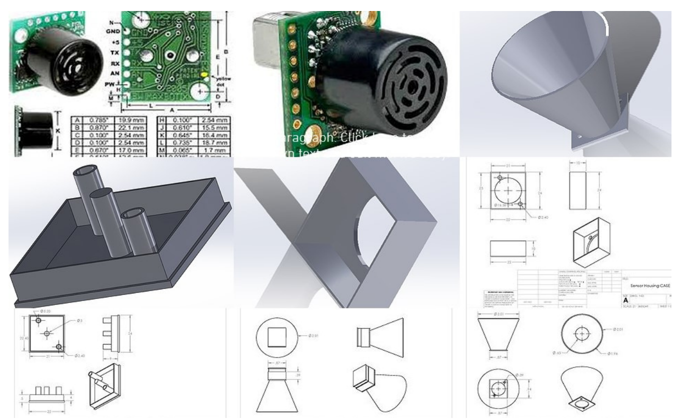

Figure 6. Example of the Housing Design for the Ultrasonic Sensor Controlled by Arduino

A sturdy and efficient design was supposed to be printed on the rapid-prototyping Makerbot printer. Given a specific sensor, students were asked to work in teams to design housing with two degrees of freedom—two rotations necessary for positioning. With this project, students integrated the study of processor-controlled sensors with the design of mechanical components and the use of design/drawing software.

Conclusions

Low-cost hardware platforms are gaining popularity among students and instructors. As Arduino microcontrollers and Raspberry Pi processors secure more room within a diverse range of academic courses, from programming and embedded systems to communications and mechatronics, students become more confident in using knowledge and devices from their hobbies in actual classroom environments and vice versa. The availability of open source code contributes to the development of a wide community of users and helps to connect people with various backgrounds, from experts to experimentalists. Combinations of these low -cost hardware platforms with XBee communication modules and sensors opens the door to a vast area of applications, and facilitates the low-cost wireless connectivity for a variety of processes, such as those in machinery, physics experiments, biomedical systems, and consumer-related applications. The same platforms can be used as instruments for teaching various courses, enabling integrated software and hardware learning environments, may be used to develop capstone projects in which students can show their creative side and apply their academic skills to projects related to their own interests, and can also be used for undergraduate research projects, empowering students with portability, flexibility of design, and access to affordable hardware and software means.

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