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Contact us:

Philip D. Weinsier, Ed.D.

Editor-in-Chief
Bowling Green State University-Firelands
One University Drive
Huron, OH 44839
Office: (419) 372-0628
Email: philipw@bgsu.edu

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EDITORIAL OFFICE:

Philip D. Weinsier, EdD
Editor-in-Chief
Office: (419) 372-0628
Email: philipw@bgsu.edu
Department of Applied Sciences
Bowling Green State University-Firelands
One University Drive
Huron, OH 44839

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TABLE OF CONTENTS

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Combining Engineering and Engineering Technology Programs into a Single Capstone Design Sequence

D. Blake Stringer, Kent State University; Maureen McFarland, Kent State University

Abstract

In this paper, the authors describe the development of a two-course capstone sequence in aircraft design that combines two programs: aerospace engineering and aeronautical systems engineering technology. Also briefly summarized are: the difference between an engineering and engineering technology curriculum and the suitability of each to the entire spectrum of engineering careers; the combined lack of student exposure to engineering and engineering technology as a missed opportunity to enhance graduate preparedness for entering the workplace; and, how the authors attempted to overcome this using a combined aerospace capstone sequence that covers a variety of topics, including technical design, product development, process development, and non-technical aspects such as legal/regulatory and value proposition. Finally, the authors present a link between the capstone sequence and the ABET outcomes, showing how the overall design experience meets these outcomes, while significantly enhancing the students' professional and technical skills. This strategy is still being implemented and will require three to four iterations to adequately assess the success of the sequence.

Introduction

The purpose of the capstone experience of any engineering technology and engineering (ETE) curriculum is to combine all elements of the students' education into an integrative experience that exposes them to a complex problem-solving environment. This is the final milestone preparing students for entry into the workplace. In many engineering curricula, the capstone takes the form of a comprehensive design project, as prescribed by ABET [1, 2]. The size and scope of the design can vary over a wide range of projects: paper designs, prototypes, design-build competitions, customer-specific collaborative designs with industry, etc. All of these projects provide intrinsic value to the student and the capstone process. An important developmental aspect of the capstone project for students is to develop the ability to work effectively in teams. Due to the nature of curricular requirements, in many cases, the teams consist of other engineering students, from either the same discipline or one that is closely related. The relative lack of diversity is an unrealistic simulation of the workplace environment and can be a significant disadvantage. This has been identified by the American Society of Engineering Education and ABET as problematic [3].

Why Combine ETE Capstones?

What are the benefits of combining ETE programs in the capstone? The capstone course (or courses) is a culmination of the academic program that allows students to integrate and apply their knowledge in support of a project that is representative of what they might encounter in the workplace [4-6]. As such, a combined course would be more representative of industry. Engineering technologists and technicians are equally important in the design and development process, since they manufacture and support the end product. Design is more than the technical design of the product; it includes the design of the manufacturing, documentation, and deployment processes as well. This is often defined as integrated product and process development [7]. Combining the two disciplines in the university capstone environment provides a significant benefit to the learning experience of students in both ETE disciplines as well as providing a better-rounded and better-prepared entry-level employee for the workplace. It enhances the capstone experience and better replicates the engineering workplace. Finally, it supports ABET student outcomes for both engineering and engineering technology, while focusing on the professional skills development of the students [1, 2].

ETE in Academia

The uniqueness of this capstone proposal lies in its combination of engineering and engineering technology disciplines. This necessitates further discussion of the similarities and differences between the disciplines. The discussion of engineering versus engineering technology has emerged recently, especially in the current environment of highly multidisciplinary projects, solving complex problems, and requiring advanced manufacturing capabilities [8]. The word versus is used appropriately, because the trend still exists in industry today [9]. Many engineering students are not exposed to engineering technology programs while in school. Indeed, in this paper, the authors present a cursory review of several institutions, and none of the top research institutions had colleges with both disciplines combined.

The difference between the two programs of study stems from the famous Grinter Report of 1955 [10]. This report, from the American Society of Engineering Education, charted the trajectory of engineering education as it has been defined for the past 61 years. Prior to 1955, engineering was considered an art, and practical application courses were integral to this curriculum. As the Cold War technology races began, the Grinter Report charted a new curriculum with emphasis on math and science, an engineering core of subjects, highly educated faculty, and research. This current model is undoubtedly very familiar to academia today. Engineering technology curricula arose in the 1960s to recover the practical and applied applications lost as a result of the Grinter initiatives [8]. The question then becomes, "What is the difference between engineering and engineering technology?" The answer is presented in Table 1, which is drawn from several sources but most notably (almost verbatim) from ASME [11].

ETE Review

To get a sense of other universities' approaches to ETE curricular programming, a review was conducted using the online academic websites of several universities across the U.S. The first group consisted of the top 10 aerospace/aeronautical/astronautical engineering graduate schools, as ranked by *U.S. News and World Report*. The second group consisted of six universities that are peer institutions to the authors' university, as well as the authors' university itself. The third group contained five universities that university leadership considers to be aspirational institutions for certain areas of distinction. The last group consisted of a survey of the public institutions within the state of Ohio. A total of 32 institutions were examined. Table 2 lists these institutions by grouping and provides the current ranking of the institution. Rather than list each university by name, the institutions are listed by rank and state. The top-10 ranking is specific to the aerospace disciplines. Other rankings are provided by *U.S. News and World Report* for the university as a whole. If the university has a Tier 1 ranking, the rank is provided. Otherwise, the university is ranked as Tier 2, since the numerical ranking is not published online. Some institutions have the same ranking. Table 2 also specifies whether the institution has an engineering program or an engineering technology program. An asterisk appears by the name of the institution if both ETE programs exist, but are housed in different colleges or other units. The programmatic information was obtained by reviewing each institution's academic websites. These website reviews were conducted between April 5 and 7, 2016.

Table 1. ETE Curricular Differences

Program Characteristics	Engineering	Engineering Technology
Technical Courses	Stress the underlying theory and analysis techniques, as well as current and potential design applications	Stress application of current engineering knowledge and design methods in the solution of engineering, business, and industrial problems
Laboratory Courses	Laboratory courses are a significant and integral component of both programs. They are designed to develop student competence in the application of experimental methods and to provide the physical bridge between physical principles and theories and the actual complexities and behavior of solid, fluid, and thermal systems.	
Design Courses	Emphasis on general design principles and analysis tools applicable to a wide variety of emerging or breakthrough problem solutions	Emphasis on the application of design standards and procedures to complex contemporary problems
	Both focus on hands-on design experiences using real world industry problems and sometimes student design competitions. Although almost all design work is done in teams in both programs, more special opportunities can exist in engineering programs for independent research-based design/development studies.	
Program Fundamentals	Require integral and differential calculus, multivariable calculus, and differential equations as well as basic science courses.	Require integral and differential calculus, as well as appropriate depth in the basic sciences.

Table 2. ETE Institutional Review

Top Aerospace Engineering Schools *US News and World Report* [12]			
2016 Rank	State of Institution	Engineering	Eng Tech
1	Massachusetts	▪	
2	Georgia	▪	
2	California	▪	
4	California	▪	
4	Michigan	▪	
6	Indiana*	▪	▪
7	Texas	▪	
8	Colorado	▪	
8	Illinois	▪	
10	Texas*	▪	▪
10	Maryland	▪	

Peer Institutions and Authors' University			
2016 Rank	State of Institution	Engineering	Eng Tech
135	Ohio	▪	▪
175	Ohio – Authors' university	▪	▪
187	Texas*	▪	▪
187	Michigan		▪
Tier 2	Georgia		
Tier 2	Texas	▪	▪
Tier 2	Utah	▪	

Aspirational Institutions			
2016 Rank	State of Institution	Engineering	Eng Tech
47	Pennsylvania*	▪	▪
61	South Carolina	▪	
115	Pennsylvania	▪	▪
156	Florida	▪	
156	Virginia	▪	

Ohio Public Institutions (excluding Ohio universities listed above)			
2016 Rank	State of Institution	Engineering	Eng Tech
52	Ohio	▪	
82	Ohio*	▪	▪
140	Ohio	▪	▪
185	Ohio		▪
Tier 2	Ohio	▪	▪
Tier 2	Ohio*	▪	▪
Tier 2	Ohio	▪	▪
Tier 2	Ohio	▪	
Tier 2	Ohio	▪	▪

*Programs not within the same college/unit

The results of this review are interesting and highlight a potentially missed opportunity between the ETE disciplines in academia. The top 10 schools are almost exclusively engineering with no curricular mix of engineering and engineering technology. Those institutions rated as Tier 1 or as aspirational contain a similar mix, heavy on engineering only. The Ohio public and peer institutions almost mirror each other in the first four categories. This makes sense intuitively, since Ohio is a state in the industry-heavy Midwest and Rust Belt region. Peer institutions would also be expected to have several equal programs. One additional note is that these also align well with the Tier 2 institutions. Of the 32 total institutions considered, almost 50% are exclusively engineering. Only 25% of the total have ETE programs in the same unit. The other 25% either do not have such ETE programs, only have an engineering technology program, or the ETE programs are housed in different units. In all cases, the authors could not find any evidence linking the capstone courses of the engineering and engineering technology programs at their respective institutions. Some ETE programs did, however, share lower-level courses.

The reader should also note how, as the perceived rankings get higher (top 10, aspirational, Tier 1), the percentage of ETE programs decreases. Those units with a larger mixture of ETE programs tend to be lower ranked. This would seem to substantiate the perceived bias between disciplines and reinforce the notion that they should remain separate. As presented in Figure 1, the lack of interaction between these two disciplines at the collegiate level is problematic. First, it reinforces a bias against engineering technology graduates. Second, these two disciplines are synergistic: both are required to design, develop, produce, and support new technology. Third, the lack of interaction does not provide exposure of each discipline to the other prior to entering industry. This is a key component of the workplace environment that, in most cases, is completely missing from the academic experience.

ETE in the Profession of Engineering

In 2010, a survey of 200 engineering companies revealed that greater than 80% of them hire engineering technology graduates to occupy engineering positions not defined as senior, design, or research. When including those higher-level positions, over 60% of the companies surveyed used engineering technologists to fill those positions as well. Approximately 67% of the companies surveyed saw no significant distinctions between assigning roles and responsibilities based upon the degree obtained. When asked about significant differences between the capabilities of engineers and engineering technologists, 70% of the respondents saw little to no distinction between the two [8].

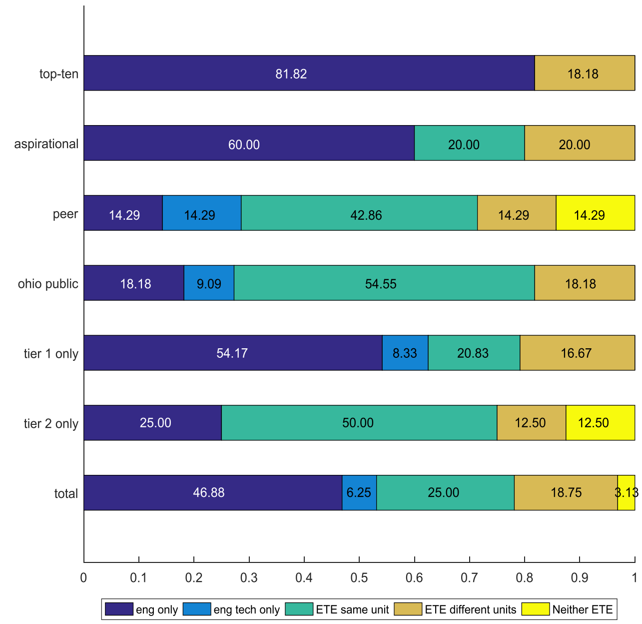

Figure 1. ETE Institutional Review Results

Figure 2 provides a good example of the synergy between the two ETE paths. It provides a list of the "engineering" career functions [11]. The figure highlights those functions typically completed by engineers and those typically executed by engineering technologists.

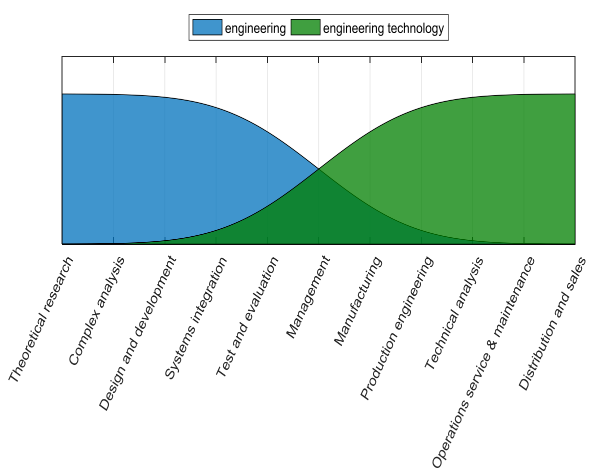

Figure 2. Engineering Career Functions

Capstone Requirements and Structure

The literature is full of papers discussing almost every aspect of a capstone design experience. According to recent studies in the literature, approximately 71% of the engineering capstone courses in the U.S. include some form of industry-sponsored project [4, 13]. Some capstones use projects that tend to be more altruistic in nature or to support communities in need or disadvantaged populations [14]. Some are design-builds such as the AIAA design, build, and fly, the American Helicopter Society student design, or the SAE Mini-Baja competitions [15-17]. The literature and ABET have defined the typical characteristics of the capstone experience. According to Dutson et al. [18], the design should be: 1) challenging, 2) able to be completed in the allotted time, 3) require a knowledge of the state-of-the-art and the application of theory, and 4) able to meet certain standards or criteria.

McGoron et al. [19] believe that, the course content of the design course(s) should include the following: 1) identify the need; 2) generate solution concepts and measures to evaluate them; 3) review the literature documentation; 4) prototype the concepts; 5) identify the key features of the design implementation; 6) communicate the solution and decision-making process; and, 7) engage in project management. In design pedagogy, the general trends of capstone design courses have changed significantly [20, 21]. Courses now tend to run the course and project in parallel as well as provide a lab section for students to work on the project. The duration of the capstone has extended in most cases to encompass a complete academic year. The number of students on a design team has trended smaller. The designs themselves are typically smaller and based upon industry associations. Lastly, the priority of topics has also shifted away from oral and written communication and more toward ethics and project management.

Combined Aerospace Capstone Sequence

The aircraft design capstone is different in many respects. First, an aircraft is designed differently from other systems. There is a "backward" nature to the design, because of the sensitivity of the weight of the aircraft to performance parameters [22]. Aircraft weight affects all aspects of the design. Aircraft are a complex system of systems that must work together, with potentially life-threatening consequences to a large number of people at once [23]. The design process is highly iterative from initial concept to final design. This process is normally measured in years. Aircraft must undergo more rigid requirements than almost anything else. The system includes the aircraft, training and support equipment, facilities, and personnel [23]. For example, one can learn how to operate an automobile and obtain a driver license at a very low cost. Becoming a commercial multi-engine-rated pilot instructor can cost up to $100,000 in an aeronautics program at a university, plus additional expense to become an airline transport pilot. Aircraft and maintenance programs must be certified as airworthy. Aircraft must meet rigid federal aviation regulations or military specifications. These designs become necessarily more complex and involved at every level.

The aircraft design course sequence combines the following objectives in curriculum design:

1. Merge engineering and engineering technology fields of study
2. Merge technical and non-technical aspects of aircraft design
3. Emphasize project management and structure
4. Incorporate 3D prototyping technology for the fabrication and evaluation of a design prototype
5. Incorporate real engine data from a high-bypass turbofan virtual engine bench

Merging ETE Fields of Study

The authors have already discussed the lack of synergy between ETE disciplines at the collegiate level. n merging these fields of study, a project-based design course sequence exposes students in both disciplines to the related, yet different, aspects of both fields of study. One of the authors from this current study has taken and taught several aircraft design courses at different institutions at both the graduate and undergraduate levels, and in both engineering and engineering technology.

As such, the author has personally observed the difference in focus between the two disciplines. Engineering students are much more focused on the engineering parameters of the aircraft to meet system requirements. Engineering technology students focus on the specifics of the systems to be used in the aircraft itself: fuel, environmental, hydraulic, etc. Engineers seem to take longer to get started and need more guidance during the process than engineering technology students. This latter observation has also been observed in industry [8].

Merging Technical and Non-Technical Aspects of Aircraft Design

While the technical aspects of aircraft design are important, non-technical aspects play a vital role in the development, production, and marketing of a new aircraft as well. Table 3 presents some of these non-technical aspects. Given that some of these less-technical aspects are within the spectrum of career functions encountered by engineering technology graduates, it makes sense to perform a more in-depth investigation to better replicate the workplace environment. This provides the multidisciplinary aspect.

Table 3. Some Non-Technical Aspects of Product Design

Stakeholders / Customers	Program Management	Finance
Manufacturing	Integrated Product Team	Legal & Regulatory/Safety
Value Proposition/ Marketing	Communication	Sales & Distribution
Socioeconomic Impacts/Ethical Considerations		

Emphasizing Program Management and Structure

In many cases, the capstone course is one of the only academic opportunities for students to serve on a large team, oriented toward a common goal. Failure to function effectively as a team often has significant academic repercussions. Additionally, the constricted timeline of academic coursework further serves to illustrate the importance of forming a project team quickly and establishing a realistic schedule to meet the requirements by the end of the semester(s). One of the primary goals of this study was to formulate a project-based template to guide students in managing their work schedule, milestones, and deliverables.

This course also strives to further develop the "professional skills" so often mentioned by industry and ABET as lacking in college graduates (effective communications skills, teamwork skills, etc.). According to Davis et al. [24], the attributes/professional skills indicating the quality of an engineer are: 1) motivation, 2) technical competence, 3) judgment and decision-making, 4) innovation, 5) client/quality focus, 6) business orientation, 7) product development, 8) professional/ethical, 9) teamwork, 10) change management, and 11) communication. These are especially important since both engineers and engineering technologists perform the management career function, as depicted in Figure 2.

Incorporating 3D Prototyping Technology for the Fabrication and Evaluation of Design Prototype

With the rapid proliferation of additive manufacturing, it is expected that the design teams will produce a three-dimensional prototype of their design for evaluation, analysis, and presentation, using 3D printing or other means. It is further expected that the students will eventually use these prototypes to evaluate preliminary aircraft characteristics by experimental means (i.e., aerodynamic characterization through wind tunnel experimentation). Figure 3 shows an example prototype. Again, using emerging prototyping tools is an opportunity relevant to both ETE disciplines.

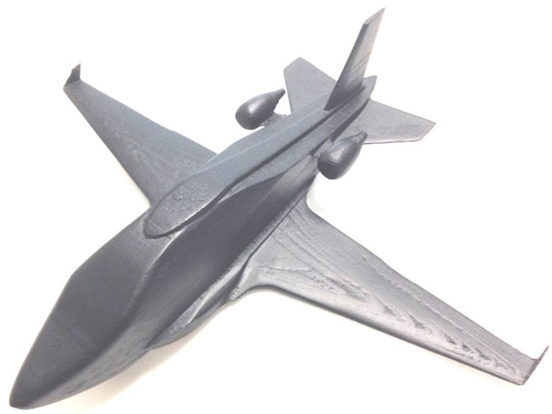

Figure 3. Example of an Aircraft Design Prototype

Incorporating Real Engine Data from a High-Bypass Turbofan Virtual Engine Bench

In 2015, the college procured a virtual engine bench by Price Induction (see Figure 4). The test bench offers a unique pedagogical and multidisciplinary tool for illustrating the behavior and performance of a turbofan engine and providing a platform for practical laboratory coursework and instruction. The virtual test bench replicates the DGEN-380 turbofan engine, a turbofan optimized for general aviation and operation below 25,000 feet. The bench uses an electronic block to simulate engine operation, consisting of the virtual engine, a full authority digital engine control microcontroller, and debug interface. This engine serves as the power plant for the design. The bench also provides information to estimate aircraft performance parameters. This technology becomes very useful for sizing the aircraft and estimating its performance.

That is not to say that the capstone would always revolve around this power plant. The use of this engine provides a manageable design project, using available technology to extract meaningful data. In subsequent offerings of the course, other types of aircraft could certainly be considered. Table 4 provides a list of the topics to be covered during the capstone sequence. The fall semester begins with an introduction to the design process and ends with completion of the aircraft's preliminary design. The spring semester delves into the step-by-step development activities and then branches more into the non-technical aspects. Both semesters end with final reports and presentations.

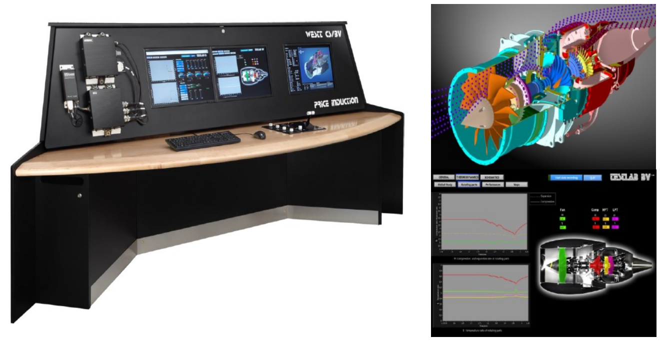

Figure 4. Virtual Engine Test Bench

Table 4. Capstone Design Topics

Fall Semester Topics	Spring Semester Topics
Introduction to the design process	Step-by-step development activities
The ETE disciplines	Aerodynamics
Professional/ethical awareness	Propulsion
Team Behavior/group dynamics	Stability and control
Project Management	Structure
Problem definition & need identification	Systems
Preliminary design	Design for manufacturing
Mission profile	Risk, reliability, & safety management
Initial sizing	Certification requirements
Geometry	Failure analysis
Response surfaces	Business development activities
Communication	Value proposition
Preliminary design review	Economic analysis
Final report	Marketing strategies
Site visit to industry	Prototyping activities
	Optimization studies
	Communication
	Final design review
	Technical paper

Impact and Results

The course sequence contributes significantly to the engineering and engineering technology programs at the authors' university. This is a unique curricular opportunity, centered on an applied, project-based learning experience, adhering closely with evolving engineering education pedagogy. The outcomes of this course directly link to all of the current student outcomes in the ABET criteria for both engineering and engineering technology fields of study. Table 5 highlights these outcomes. This capstone is still in its implementation and evaluation phase and will require three to four iterations to assess the effectiveness of the sequence proposed here. To date, the aeronautical systems engineering technology capstone has implemented four of the five design sequence objectives. Due to the newness of the university's aerospace engineering program, a cohort class has yet to progress to the senior level. The current capstone course has integrated the other four objectives during the past three course iterations with positive results. As the first aerospace engineering classes fully matriculate, the success of the sequence will be better understood.

Another important note is that these concepts work due to the nature of the aerospace capstone, which centers on the design of an aircraft or spacecraft, which is a complex system with life-altering implications. These are similar to other systems on the level of ship, power plant/power grid, or building design of other engineering disciplines such as marine, mechanical, nuclear, or civil engineering. For other capstones, it is unclear how successful a merging of ETE students would be for smaller design projects. It may very well be that such a merger would be problematic in other instances.

Table 5. ABET Student Outcomes

Engineering student outcomes* [1]	Engineering technology student outcomes [2]
An ability to apply knowledge of mathematics, science, and Engineering	An ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities
An ability to design and conduct experiments, as well as to analyze and interpret data	An ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies
An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	An ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes
An ability to function on multidisciplinary teams	An ability to design systems, components, or processes for broadly -defined engineering technology problems appropriate to program educational objectives
An ability to identify, formulate, and solve engineering problems	An ability to function effectively as a member or leader on a technical team
An understanding of professional and ethical responsibility	An ability to identify, analyze, and solve broadly-defined engineering technology problems
An ability to communicate effectively	An ability to apply written, oral, and graphical communication in both technical and non-technical environments; and an ability to identify and use appropriate technical literature
The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and social context	An understanding of the need for and an ability to engage in self-directed continuing professional development
A recognition of the need for and ability to engage in lifelong learning	An understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity
A knowledge of contemporary issues	A knowledge of the impact of engineering technology solutions in a societal and global context
An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	A commitment to quality, timeliness, and continuous improvement

*The authors are aware of the current proposals for substantive change to the ABET criteria. When approved, the courses will link accordingly.

Conclusions

In this paper, the authors have summarized the development and implementation of an aerospace capstone sequence for both engineering and engineering technology students through the following:

- Highlight the importance of both engineering and engineering technology programs to the profession of engineering.
- Highlight the curricular differences between the two disciplines.
- Highlight the current lack of synergy between ETE curricula through a review of 32 institutions across the U.S.
- Highlight the indistinguishability of graduates of either program of many engineering companies.
- Highlight some of the intrinsic differences between aerospace designs and other designs, and the necessity of a more robust capstone experience.
- Highlight the capstone design objectives and lesson topics.

The implementation of this sequence is still in progress, but in developing an aerospace capstone that combines engineering and engineering technology, the institution not only provides an experience for students that better replicates the multidisciplinary workplace environment, but it also addresses the aforementioned concerns highlighted by industry [8].

Acknowledgments

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Biographies

D. BLAKE STRINGER is an assistant professor of aeronautics at Kent State University. Prior to joining the faculty at Kent State, Dr. Stringer served in the Army for 20 years as an army aviator, West Point faculty member, and research engineer. He holds a bachelor's degree in aerospace engineering from the U.S. Military Academy, a master's degree in aerospace engineering from Georgia Tech, and a doctorate in mechanical and aerospace engineering from the University of Virginia. His research interests include unmanned aerial systems, the aerodynamics and performance of vertical-axis wind turbines, rotating mechanical components, and engineering education pedagogy. Dr. Stringer may be reached at dstring1@kent.edu

MAUREEN MCFARLAND is the aeronautics senior program director and an assistant professor at Kent State University. Prior to joining the faculty at Kent State, Prof. McFarland served in the Marine Corps as a navigator at which time she transitioned to the Marine Corps Reserve, retiring after 20 years' of service. She holds a bachelor's degree in aerospace engineering from the U.S. Naval Academy, a master's degree in business from Boston University, and is a doctoral candidate in educational psychology at Kent State University. Her research interests include assessment, effective teaching practices using instructional technology, and engineering education pedagogy. Dr. McFarland may be reached at mmcfarl2@kent.edu

INTEGRATING COBOTS INTO ENGINEERING TECHNOLOGY EDUCATION

Ana M. Djuric, Wayne State University; Vukica Jovanovic, Old Dominion University;
Tatiana V. Goris, Purdue University; Otilia Popescu, Old Dominion University

Abstract

Collaborative robots, or CoBots, have recently become embedded in many manufacturing and assembly systems, as they can be safely integrated directly in systems that use manual labor. Exploiting the efficiency of automated operations and the flexibility of manual operations in one process can improve productivity and worker job satisfaction. Their application is now gaining more attention in manufacturing systems for food processing, automobiles, transportation, aerospace, and naval applications. Current CoBot education and training opportunities are rare or non-existent in university environments. In response to this need, the authors of this current study developed several CoBot modules to integrate into current robotics and mechatronics courses. In this paper, we present one common module slated for integration. This module is about modeling and validation of Baxter collaborative robot kinematics using MATLAB tools. Through the validation and visualization of the kinematic equations, students will be able to connect robotic and mechatronic theory with different applications using the latest technology.

Introduction

The term CoBot comes from the combination of the words collaborative and robot. The main purpose of this robot is to enable physical interaction among humans and robotics systems in the same work cell [1]. Various industries have seen growth in the applications of such robots, ranging from food processing to aerospace. Such technological development is not to replace humans, but rather to see how robotic technology can be used alongside manual labor, which is used (and will probably continue to be used into the future) in various manufacturing and assembly operations. Because CoBots work side by side with humans, a new technology designed to increase safety was developed. Some of the new features added to these robots include a more ergonomic and human-friendly design, which is achieved through curved surfaces with generous fillets at all edges and longer vertices. Another feature, added for safety, limits the power and the velocity of the joints. Moreover, better collision-detection capabilities have been developed [2]. Today, most companies are looking forward to this technology, as it would save money that is currently being spent on building separate cages and isolated workspaces for classic robots [3]. Also, the portability and capacity to work in a reconfigurable environment makes collaborative robots the best choice for dynamic companies that need to change their assembly lines to respond to ever-growing customer expectations.

One of the main methodologies for the design, manufacture, and success of CoBots is founded on four main principles: design and integration principles focused on the system level; features that are related to its use on the manufacturing workplace level; features that are related to machine constraints; and, features that are related to the work with human workers [4]. Each of these different levels holds its own constraints, when it comes to layout design, possible configurations, safety requirements, and worker training [4]. For those reasons, there is a need to better understand their kinematic structure and associated equations. The kinematic equations for the 7-degree-of-freedom collaborative robot Baxter was presented by Silva et al. [5]. This model was validated using an experimental procedure. Hundreds of thousands of CoBots are already integrated into manufacturing systems worldwide. Hence, there is a proven need for curriculum development in engineering technology education that would follow this industry trend. Understanding such different robotic technology has to take into account all of these four main aspects of CoBot technology: from systems perspective to workplace design to mechatronics systems in the device itself and to the human-robot integration and collaborative aspect. Although various CoBots are currently used for recruiting and research purposes, they are not used in mainstream engineering technology courses, since the technology is still not available at many community colleges and undergraduate engineering technology programs.

In response to this need, several CoBot modules that will be integrated into current robotics and mechatronics courses were developed. In this paper, the authors present one common module that will be integrated into both robotics and mechatronic courses. This module is about modeling and validation of Baxter collaborative robot kinematics using MATLAB tools. Students will learn how to model and visualize kinematic equations, understand the main principles in industrial robotics and mechatronics, and relate the theory to the application through hands-on activities.

Baxter Kinematic Model

Baxter is the collaborative robot made by the Rethink Company. The Baxter arms have seven rotational joints in each arm. Figure 1 shows that they are labelled— starting from the shoulder—as s0, s1, e0, e1, w0, w1, and w2 [6].

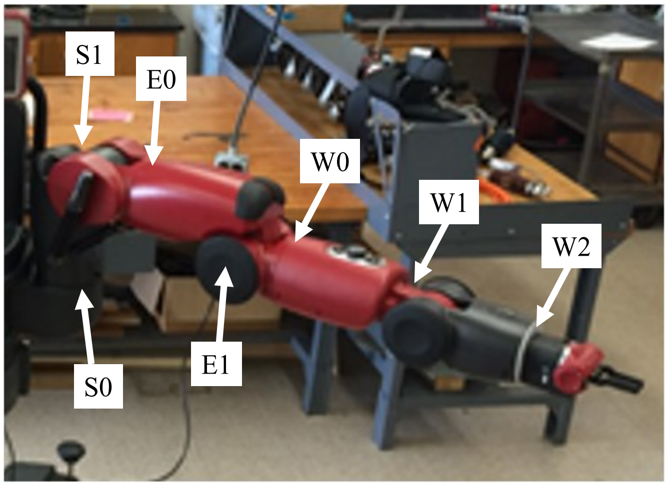

Figure 1. The Arms of the Baxter Robot with Seven Joints in Each Arm [5]

Using robot kinematic theory, the Baxter mathematical model was developed and validated [5]. This model is used in the CoBot common module that will be integrated into both robotics and mechatronic courses. The model was developed using five steps.

Step (a): Development of the Baxter kinematic diagram (see Figure 2) [5].

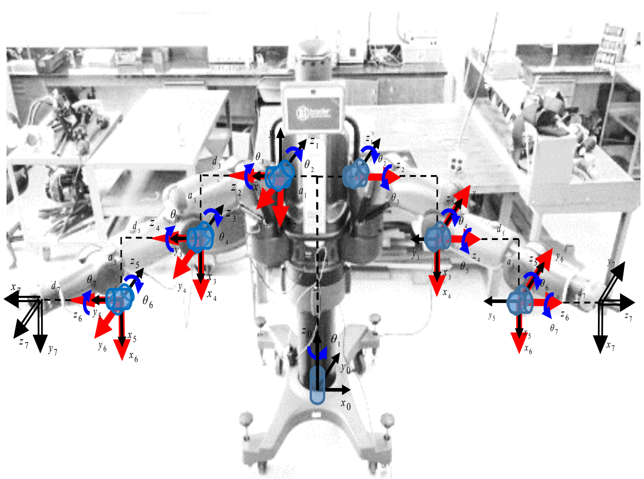

Figure 2. Baxter Kinematic Diagram with All Coordinate Systems Assigned

Step (b): Development of the Denevet-Hartenberg (D-H) parameters: a_i is the link length; d_i is the link offset; è$_i$ is the joint angle; α_i^L is the twist angle for the left arm; and,i α_i^R s the twist angle for the right arm (see Table 1) [7].

Table 1. Baxter CoBot Denevet-Hartenberg Parameters

i	d_i	è$_i$	a_i	α_i^L	α_i^R
1	d_1	$\theta_1^L = 0^\circ$, $\theta_1^R = 180^\circ$	a_1	−90°	90°
2	0	$\theta_2^L = 90^\circ$, $\theta_2^R = -90^\circ$	0	90°	−90°
3	d_3	$\theta_3^{LR} = 0^\circ$	a_3	−90°	90°
4	0	$\theta_4^{LR} = 0^\circ$	0	90°	−90°
5	d_5	$\theta_5^{LR} = 0^\circ$	a_5	−90°	90°
6	0	$\theta_6^{LR} = 0^\circ$	0	90°	−90°
7	d_7	$\theta_7^{LR} = 0^\circ$	0	0°	0°

Step (c): Determine the position and orientation of any frame i with respect to frame i-1, using the homogenous transformation matrices ${}^{i-1}A_i$ [see Equation (1)]. Using the D-H parameters from Table 1 and Equation (1) for i=1,2,…,7, all seven transformation matrices were calculated:

$$ {}^{i-1}A_i = \begin{bmatrix} \cos\theta_i & -\cos\alpha_i \sin\theta_i & \sin\alpha_i \sin\theta_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\alpha_i\cos\theta_i & -\sin\alpha_i\cos\theta_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

Step (d): Multiplication of two matrices, which were the result of the previous transformation. Multiplication starts at the beginning, from joint 1, and goes all the way to the end effector. After that stage, Equations (2) and (3) for the forward kinematics of both arms were determined:

$$ {}^0A_7^L = {}^0A_1^L \, {}^1A_2^L \, {}^2A_3^L \, {}^3A_4^L \, {}^4A_5^L \, {}^5A_6^L \, {}^6A_7^L \quad (2) $$

where, ${}^0A_7^L$ represents the left arm end-effector frame 7 position and orientation with respect to the base frame 0;

$$ {}^{0}A_{7}^{R} = {}^{0}A_{1}^{R}\ {}^{1}A_{2}^{R\,2}\ A_{3}^{R\,3}\ A_{4}^{R\,4}\ A_{5}^{R\,5}\ A_{6}^{R\,6}\ A_{7}^{R} \qquad (3) $$

where, ${}^{0}A_{7}^{R}$ represents the right arm end-effector frame 7 position and orientation with respect to the base frame 0.

Step (e): Using MATLAB tools, different end-effector positons were calculated for selected joint angles. In this step, students can visualize the CoBot kinematic equations. Two points were used to illustrate the procedure and importance of the module. First, the left arm joint 1 is moved 30º (0.523599 radians), and its position is calculated and visualized using MATLAB (see Figure 3). Second, the right arm joint 1 is moved 30º (0.523599 radians), and its position is calculated and visualised using MATLAB (see Figure 4).

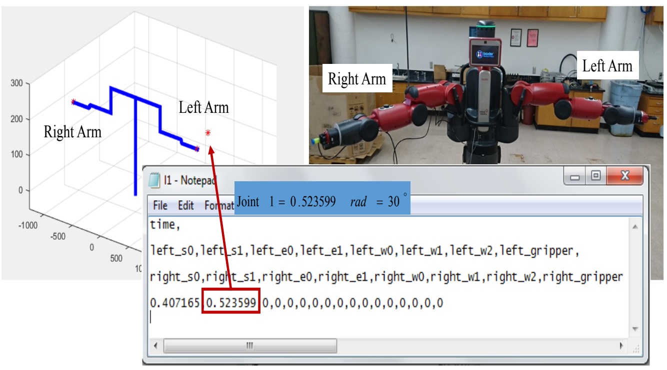

Figure 3. Baxter Left Arm Joint 1 Position Calculation Using MATLAB

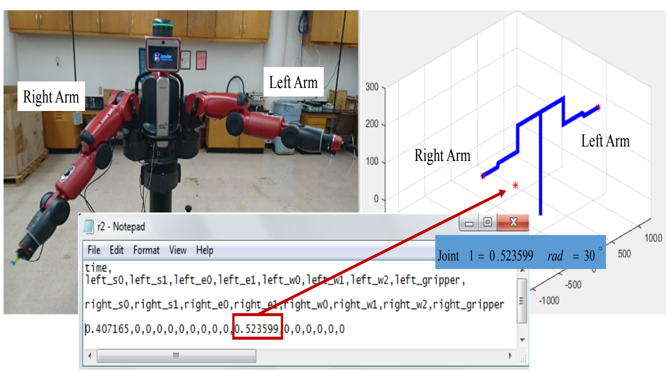

Figure 4. Baxter Right Arm Joint 1 Position Calculation Using MATLAB

Baxter Kinematic Module Integration in Current Robotics and Mechatronics Courses

The Baxter kinematic module was developed based on learning objectives of the two courses. The goal was to use and reuse the same module in different courses. The success of module integration was shown through mechatronic and industrial robotic course objective satisfaction.

Learning Objectives for the Robotics Course

Table 2 lists the course learning objectives. The integrated CoBot module can be used for almost all of the objectives listed.

Learning Objectives for the Mechatronics Course

Table 3 presents the proposed learning objectives for the mechatronics course. The integrated CoBot module can be used for almost all of the objectives listed.

Advantages of Integrating Collaborative Robots into an Engineering Curriculum

The importance of integrating collaborative robotics into engineering courses is described in the literature [8]. The collaborative robotics module presented in this paper can be integrated into existing courses in engineering technology programs. By using CoBots in the engineering technology lab, students are exposed to industrial robotics in a much safer way than when dealing with full-scale, large industrial robots. Students reported satisfaction with the hands-on experience in their interaction with robots and simulations, which will show them results derived from theory and mathematical calculations. These robots can also be used for research and educational outreach, since many of them are portable.

Conclusions

CoBot technology has been experiencing strong growth in different areas, such as ground transportation, food processing, car manufacturing, and naval or aeronautical engineering. In response to the new technology, the authors developed a CoBot learning module to integrate into current robotics and mechatronics courses. The learning module was developed using a collaborative Baxter robot, robot kinematic theory, and MATLAB tools. This module utilizes theory and hands-on practice to integrate and visualize complex math and physics phenomena. Through the validation and visualization of the kinematic equations, students are able to connect the robotic and mechatronic theory with different applications using the latest technology.

Table 2. CoBot Module Satisfaction of Industrial Robotic Learning Objectives

	Industrial Robotics Course Learning Objective	Industrial Robots	CoBots
1	Determine different type of industrial robots and their applications.	√	√
2	Perform mathematical analysis of objects position and orientation in space using homogeneous transformation matrix.	√	√
3	Mathematical modeling of robot kinematic structure using Denavit-Hartenberg representation.	√	√
4	Solving the direct kinematic problem for multi DOF kinematic structures with different type of joints.	√	√
5	Solving the inverse kinematic problem using analytical and geometric approaches applied for multi DOF manipulators.	√	*Not applicable now because of complexity*
6	Establish Jacobian matrices and calculate appropriate transformations for given degrees of freedom	√	√
7	Apply computer simulation and off-line programming software, such as Workspace LT.	√	*Currently this is not possible*
8	Evaluate safety issues for robot workspace layout design (collision detection, path generation, robot Workenvelope generation, etc.).	√	√
9	Communicate effectively in oral and written formats.	√	√
10	Select industrial robotic problem, solve it using the robotic theory, prepare engineering report and present.	√	√

Table 3. CoBot Module Satisfaction of Mechatronic Learning Objectives

	Mechatronics Course Learning Objective	Industrial Robots	CoBots
1	Design mechatronic system and its primary elements	√	√
2	Simulate movement of mechanisms in computer aided modelling	√	√
3	Model different components used in mechatronic system design	√	√
4	Control different actuation systems used in mechatronic systems	√	√
5	Practice basic serial communication and interfacing of electrical control elements	√	√
6	Program microcontroller and collect data from sensors and control actuators	√	√

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Biographies

ANA M. DJURIC is an assistant professor of engineering technology at Wayne State University. She teaches various courses in mechanical and manufacturing engineering technology. Her research area is in industrial robotics. She has published over 50 journal and conference papers. In 2007, Dr. Djuric received her PhD in mechanical engineering from the University of Windsor, Canada. She also holds an MASc in industrial and manufacturing systems engineering from the University of Windsor (1998) and dipl.ing in mechanical engineering from the University of Belgrade, Serbia (1993). Dr. Djuric may be reached at ana.djuric2@wayne.edu

VUKICA M. JOVANOVIC received her dipl.ing and MSc in industrial engineering from the University of Novi Sad, Serbia. She received her PhD in technology from Purdue University, while working as a PhD student in the Center for Advanced Manufacturing. She is an assistant professor of engineering technology in the Frank Batten College of Engineering and Technology at ODU. She is the faculty lead of the Mechatronics Systems Design area of specialization in the Engineering Technology Department. She teaches classes in the areas of mechatronics and computer-aided engineering. Her research interests include mechatronics, digital manufacturing, product lifecycle management, manufacturing systems, and engineering education. Dr. Jovanovic may be reached at v2jovano@odu.edu

TATIANA GORIS is a clinical assistant professor at Purdue Polytechnic Institute. She teaches various courses in mechanical and electrical engineering technology. In 2012, Dr. Goris received her PhD in technology from Purdue University. She also holds an MS degree (1999) in electronics engineering from Taganrog Institute of Technology, Russia. Her research interests include the cognitive aspects of learning in engineering and technology education. Dr. Goris may be reached at tgoris@purdue.edu

OTILIA POPESCU is an assistant professor in the Department of Engineering Technology at Old Dominion University. She received her engineering diploma and MS degree from the Polytechnic Institute of Bucharest, Romania, and PhD degree from Rutgers University, all in electrical and computer engineering. She previously worked for the University of Texas at Dallas, the University of Texas at San Antonio, Rutgers University, and the Politehnica University of Bucharest. Her research interests include the general areas of communication systems, control theory, and signal processing. Dr. Popescu may be reached at opopescu@odu.edu

ALTERNATIVE ENERGY POWERED COMPUTER LAB AND GREEN TECHNOLOGY ON CAMPUS

Yu Cai, Michigan Technological University; Brice Downey, Michigan Technological University;
Matthew Schultz, Michigan Technological University

Abstract

People around the world care about sustainability related issues, including energy consumption, environmental protection, and global warming. Green energy sources is an interesting topic with increasing importance. In this study, the authors designed an experiment to answer the question of how viable solar and wind alternative energy sources could be used to power a computer lab in a university setting. Tests were conducted to measure the potential electricity these sources could generate. Energy consumption data were collected from PCs, thin clients, and LCD monitors under varying workloads. The data were used to calculate how well each power source could potentially power lab setups with varying configurations and workloads. In addition to this green IT project, there are a number of green technology projects at the authors' home institution to promote sustainability research and education activities, as there is a strong move towards going green on campus. Many of these projects are managed and operated by students. In this paper, the authors summarize on-campus student activities related to green technology over the past few years.

Introduction

Sustainability has received tremendous interest in the past few decades across the world. Sustainability is often defined as "meeting the needs of the current generation without compromising the ability of future generations to meet their own needs" [1]. The term is often used in reference to the potential longevity of vital environmental and human ecological systems, such as climate, agriculture, forestry, civil, and human communities in general [2]. At the authors' home institution, there is a strong move toward going green on campus. Sustainability is one of the core values of the university. Many faculty and students on campus realize their civic and social responsibilities and want to develop and use technologies in working towards a sustainable future. Many projects are proposed and conducted by students, faculty, and staff to help reduce energy consumption and find ways to cut the usage of other resources.

This paper is organized into two main parts. The first part is a detailed description of a green technology project named the Alternative Energy Powered Computer Lab project. The second part is an introduction of student self-managed green technology research and educational activities at the authors' home institution. Alternative energy comes in many different types. The main categories are geothermal, wind, solar, hydropower, and biomass. The primary mechanism for the production of electricity using these methods is the creation of a force that moves the blades of a turbine. The turbine then produces electricity by electromagnetic induction. The exception to this are photovoltaic solar cells, which generate electricity directly. For the purpose of an alternative energy lab, the concentration was put on the viability of solar and wind.

One of the key factors of how effective solar and wind power are depends on the location where they are deployed. Wind turbines require a location with high wind power density (WPD) [3]. WPD is the measurement of the available wind energy that can be harnessed to produce electricity, measured in watts per meter squared (W/m^2). Solar PV cells require a location with a significant amount of unobstructed sunlight.

There are many advantages of using alternative energy sources over traditional electricity generation methods. Alternative energy sources, with the exception of biomass, do not require fuel to produce energy; they harness natural forces to do useful work. The advantage of this is twofold. First, the only cost after the initial investment of an alternative energy source is any maintenance and overhead of the facility or setup. This not only cuts out a significant recurring cost but also ensures that the price of the electricity is less affected by the fluctuating prices of non-renewable resources that are used for producing electricity. Second, for locations where fuel is logistically difficult to acquire or the price is significantly inflated, alternative energy becomes more viable than its traditional counterpart.

The scalability of many alternative energy systems gives them a high degree of flexibility for situations to which they can be applied. They can be used in large scale to offset the cost of power for business. For example, United Parcel Service (UPS) did exactly this in their Palm Springs, CA, location with a PV solar array that provided the location with 104.5 kilowatts of power. UPS plans to invest $18 million in on-site solar in 2017 [4].

At the same time, their ability to scale down allows alternative energy systems to be deployed in remote areas for smaller uses. In the south pacific, Via Technologies provided a solar-powered information community center to local residents in 2016 [5]. The deployment of alternative energy in such scenarios will help alleviate the digital divide that plagues the underdeveloped areas of this world. The cost of alternative energy is a major roadblock to its adoption. Conventional electricity generation has had significant efforts put forth to ensure that they are highly efficient. Making alternative energy economically competitive has been a focus for many years, but there is still much progress to be made. In a report from the Institution for Energy Research, the levelized cost of a solar PV power plant in 2017 is $144.3 per megawatt-hour (MWh); a similar cost for wind (offshore) is $221.5 per MWh [6].

For comparison, the levelized cost of a power plant using traditional coal is $100.1 per MWh, and $67.1 per MWh for conventional natural gas [6]. Despite the higher cost of alternative energy, there are many sound reasons to apply alternative energy sources to meet computing needs. Computing plays a critical role in our society. Thus, it has a special responsibility to promote sustainability. A computer lab run off green energy would not only have a reduced impact on the environment but also have the potential of reducing the long-term energy cost of the lab. The ability for alternative energy sources to power computer labs also opens up this technology to underdeveloped parts of the world. By closing the digital divide of the world, people can help provide a better quality of living for everyone.

The goal of this project was to determine the technical feasibility of using alternative energy sources, such as wind and solar, to power a computer lab in a university setting. If computer labs can be run off of alternative energy sources, the power draw of traditional methods can be alleviated. Additionally, areas such as third-world countries that do not have access to a stable electricity grid, alternative energy sources could be used to power electronics and computers.

Alternative Energy-Powered Computer Lab

The alternative energy lab used for testing purposes at the authors' home institution has two main sections. The first section is the alternative energy lab energy gathering setup. This setup consists of the alternative energy apparatus including the solar panel and wind turbine. Also included in this setup are the necessary components to make the alternative energy lab work, such as batteries and a power inverter. The second section of the alternative energy lab is the computer power use data acquisition setup. This setup consists of desktop computers and monitors of different types along with a power-consumption metering device.

Energy Gathering Setup

The energy gathering setup in the alternative energy lab was located in the DOW building on campus. The setup itself was in two parts; the first being outside to be exposed to the elements, and the second inside in a weather-controlled environment. The exterior components were located on the roof of the DOW building adjacent the internal lab setup. On the ceiling was a weather gathering station that was used by other departments. This station was optimal as a base platform to conduct research on as it allowed for the wind turbine and solar panel to be placed securely on the roof. The wind turbine was rated at 12 volts at 30 amps, and was mounted approximately 15 feet above the platform giving it optimal wind flow. A 130-watt solar panel was also mounted at a 45-degree angle and placed on the platform itself. Both the wind turbine and solar panel produced 12 volts of direct current power. This power was fed into the building to charge the battery array. A pair of 6-gauge wire ran from both the wind turbine and the solar panel into a conduit on the exterior of the DOW building. This allowed for the power generated to be moved inside into a weather-controlled environment. The wire was approximately 20 feet long and insulated and protected from the elements.

The internal setup for the alternative energy lab consisted of four sealed lead-acid batteries, a charge controller, a power inverter, a PC, and two digital multimeters. The power generated from the wind turbine and the solar panel was fed into the building through the conduit from the outside. The wind turbine had an internal charge controller and, therefore, could be directly connected to the battery array. The solar panel required an external charge controller to be connected to it and the charge controller itself was connected to the battery array. The charge controller was used to regulate the flow of power into the batteries. Without a charge controller, the batteries could be overcharged or damaged from a voltage level that is over the batteries rating level. The battery array was four 12-volt sealed lead-acid batteries. The batteries were connected in parallel to allow for 12 volts of power with a cumulative current. Each battery was rated at 55 Ah for a total of 220 Ah. The battery array was used for multiple purposes in the system. First, the battery array served as an energy storage system, which would continuously power the computer lab for a period of time even without new energy generated. Second, the battery array would smooth out fluctuations in power profiles for solar energy and wind energy. Third, the battery array would serve computing needs from the lab with various workloads.

Along with being connected to the external alternative energy power sources, the battery array was also connected to a power inverter using a pair of wires with the same gauge as used in the exterior setup. The power inverter was used to provide a means to covert 12 volts of direct current power to 120 volts of alternating current to be used by standard electronic devices such as a PC or monitor. Two digital multimeters connected to the battery array were used to monitor the internal alternative energy lab setup. These monitors had USB connections allowing them to be connected to a PC. One meter was used to measure current, and the other for voltage measurement. Each monitor was connected to a laptop computer that was plugged into a standard wall outlet. This was done to ensure that monitoring would be consistent and not interrupted by a lack of alternative energy. The software package that was included with the meters was used to record the data gathered. This software also graphs the reading in real time, whether voltage or current. The data can be exported into a software package such as Microsoft Excel to be correlated into usable results.

For the lab setup, only one of the two alternative energy sources was utilized at one time. This simplified the overall configuration and allowed the test to be conducted on a per energy source-type basis. For charging to occur, the batteries had to be drained. A standard desktop PC was connected to the power inverter to provide a load on the system. Once a test was completed, the batteries could be drained via the desktop PC to allow for charging in subsequent tests. During this discharge time, experiments were conducted on how long the batteries could sustain a single PC and monitor load. The data could then be extrapolated to find out how long the system could run and how many batteries would be needed for a viable laboratory environment. Figure 1 shows the setup of the testbed; Figure 2 shows inside and outside views of the lab.

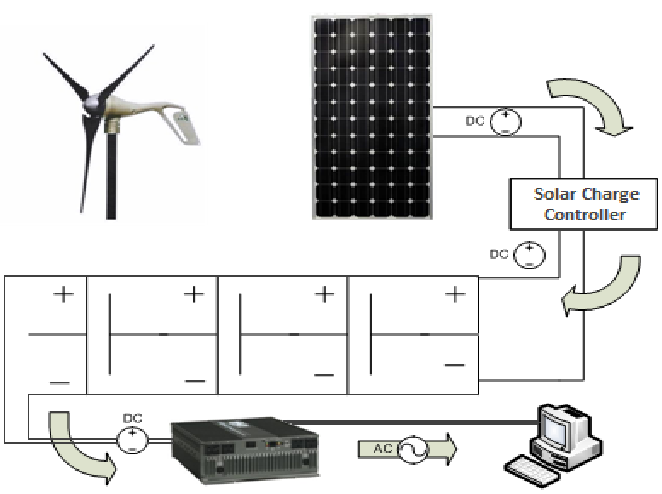

Figure 1. Project Testbed Setup

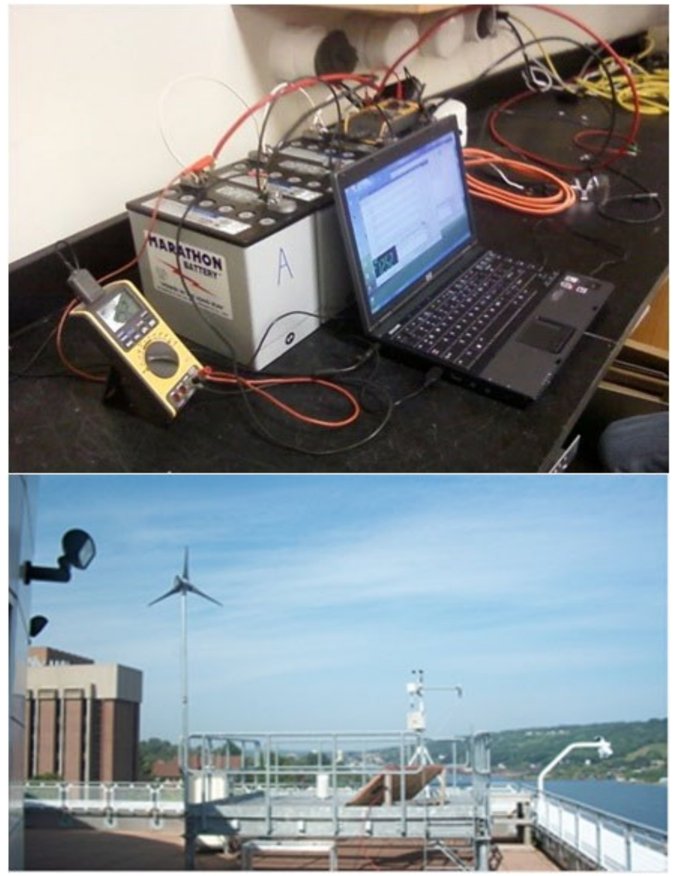

Figure 2. Inside and Outside of the Lab

Power Use Data Acquisition Setup

The second test environment was the power-use data acquisition setup. This setup was conducted in the EERC Senior Project Lab, due to space limitations in the DOW building. The purpose of this test setup was to find out how much power, on average, a standard desktop PC consumes along with a Thin Client for comparison purposes. Additionally, a CRT and an LCD monitor were measured for power consumption, along with several network devices such as a switch and a router. The tests for the power-use data acquisition setup were done using a Watts-Up-Pro power meter. This meter plugs into a standard 120V AC power outlet. One device is able to be connected to the meter at a time, unless using a power strip to conduct a test on the overall power consumption of a complete computer setup. The Watts-Up-Pro meter has a digital display of wattage along with the ability to store data to internal memory. A USB connection allows the data to be quickly pulled from the meter. Additionally, the meter comes with its own data analysis package, which can graph power consumption in time versus watts.

The lab setup consisted of multiple computers, including standard desktop PCs, thin clients, and an associated server. The standard PCs were Dell Optiplex GX620, the thin clients were HP Thin Clients, and the terminal server was a generic AMD-based system. The monitors for testing were LCD HP L1908w and CRT SUN Systems; the monitors were each 19 inches.

Custom Load Generation

Workload benchmark was required for testing the power consumption of a PC and a monitor. Both had an idle and a powered state along with a residual power state when they were shut off, yet still plugged into a power source. For load testing, it was required to have a load that emulated that of a typical computer lab environment. One approach would be to conduct the test in a live lab with power monitoring equipment. For this test, it was not viable, due to computer lab restrictions and campus policy. It was determined that custom software could be run to emulate computer load. This software could then be run to test the power consumption of both the standard PCs and the Thin Clients. The monitors' idle and powered state was based on the output they received from the connected PC. Because of this, the test had to be conducted during a powered period and calculated for the period that the monitors would actually be active.

Two custom programs were written to emulate the load required for a simulated computer lab environment. The first program, pi.exe, was written in C++ and used to approximate pi; this generated a CPU load on the system, thereby increasing the power consumption. The second program, loadtool.exe, was written in VB.NET and ran the pi.exe program on a user-defined or preset interval. With the two programs together, the test could be run to simulate the load created by a user using a PC over a given period of time. Multiple instances of pi.exe were called to create a varying load on the system. Loadtool.exe could be set for a given target CPU load as well as for a specific or random amount of time to run for each test. After the test, the program waited for a defined or random amount of time before conducting the next test. Due to the design of the Thin Client and terminal server, the Thin Client created no load of its own, outside of the processing power for the network traffic and the video rendering. Because of this, the load testing was conducted on the terminal server itself. Figure 3 shows the user interface for Loadtool.exe. There are many load-generation software packages available; however, using customized programs to generate a computer load afforded more flexibility for customizing parameters and controlling the test.

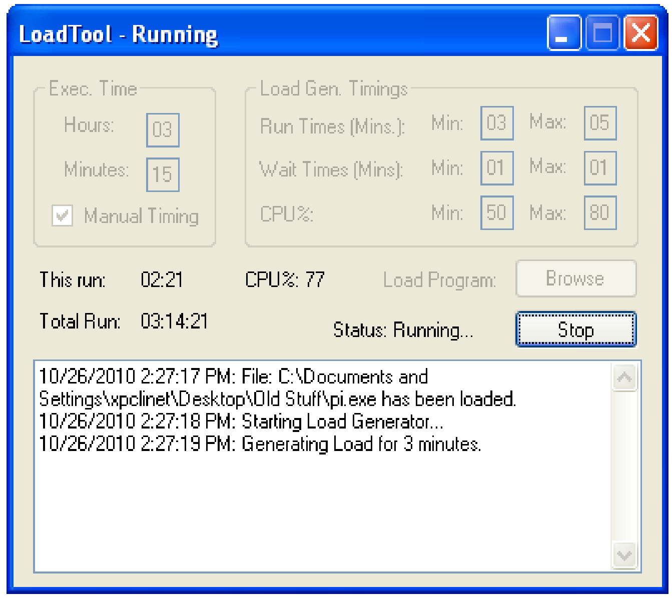

Figure 3. Loadtool.exe User Interface

Testing

Testing for the alternative energy lab was broken into two sections, as were the lab setups themselves. The first test was run on the alternative energy lab energy-gathering configuration. The purpose of these tests was to determine the amount of power that could be generated from wind and solar sources. Tests were further broken into testing either wind or solar power independently in order to determine the individual feasibility of each relative to the setup. Each energy source was then tested over a period of time with varying weather conditions to determine an average power output from the given source.

To test the power output of both the solar panel and wind turbine, two digital multimeters were used together. The first meter was connected across the first battery's terminal contacts to measure the voltage potential of the system. The second meter was connected in line from one of the wires running into the building. This causes the current flow to travel through the meter to measure amperage. With both voltage and current known, power in watts could be calculated using the formula P=VI, where P is power in watts, V is voltage in volts, and I is current in amps. The first set of tests was conducted on the wind turbine. The turbine was able to put out 12V of DC power at a maximum of 30 amps. An issue arose during testing that the digital multimeters used were rated at 10 amps maximum. The first test failed, due to a blown fuse in the meter that was measuring current. A different method for measuring current was needed to be able to calculate the power generated by the wind turbine.

Using a system with a known resistance, the test was able to be conducted by placing a copper coil in place of the multimeter. The meter was then connected to either end of the copper coil to measure the voltage drop across the known resistance. The resistance of the coil was measured using a more accurate digital multimeter. After determining the resistance of the coil, the calculation V=IR could be used, where V is voltage in volts, I is current in amps, and R is resistance in ohms. With this setup, one meter measures the voltage potential of the entire system, while the second measures the voltage drop across a known resistance. The power output (watts) of the wind turbine could then be calculated using the measured results.

Testing was conducted over a period of 24 hours per test, and the tests were repeated many times during the year. This was done to find an average power output of the wind turbine, due to the fact that some days of testing were extremely windy with gusts over 40 MPH, while other days saw relatively no wind. A sustained wind is required for the wind turbine to be able to produce usable power, so testing was conducted over a period of 24 hours to be able to record data during the times that the wind turbine was actively producing power. During the testing process, each digital multimeter was connected to the laptop for data acquisition. For the wind turbine, each meter was used to measure voltage. The software package on the laptop was used to record the voltage data versus time. A sample rate of 60 samples per minute was used to more accurately calculate the power over time for the wind turbine, as, at some points, the power output can spike for only a few seconds as the turbine itself gets up to a speed that can output useable power. The timestamps for each voltage measurement were used to correlate the data for calculations.

Testing conducted on the solar panel followed a similar process. However, during solar-panel testing, one digital multimeter was used for measuring voltage, while the other was used for measuring current. The current was able to be measured by the multimeter in the solar panel test, because the solar panel never peaked above 10 amps. This allowed for an easier calculation of power, because two calculations were not required for each data point. A sample rate of 60 samples per minute was also used for the solar panel. The solar panel generally outputs more consistent power levels, since the power generation is based on the solar energy collected. Because of this, the only changes in power output were based on the cloud cover and the angle of the sun as it changed throughout the day.

Solar testing was conducted for 24 hours at a time and on different days. The power output from the solar test was averaged to get a more realistic overall estimate of solar feasibility. The power output of the solar panel varied on a daily and hourly basis. The ideal conditions for solar energy are during peak sunlight hours of the day. At night, there is no energy production, and the solar panel charge controller actually leaches a small amount of power from the batteries for its LEDs and digital display. Several angles and orientations were tested for the optimal solar conditions on the roof. A solar tracking system would have provided the best results; however, for the test conducted, a static position was used.

After the batteries were fully charged, a test was conducted to see how long a standard PC and monitor could be run before the system would power down. The alternative energy power sources were disconnected to prevent the array from being continually charged. Timestamps were used to determine the length of time it took to fully discharge the battery array. The array could never be fully discharged, as the power inverter shuts off when the supplied voltage is less than 10 volts. Because of this, the minimum discharge voltage attained was always 10 volts for the battery array. When the power inverter shut off and the voltage was a constant value, it was determined as the amount of time the system could run off of the battery array. Once the system was discharged, a test was conducted to determine the length of time needed to fully charge the battery array using both wind and solar power. After a period of time where the maximum voltage was constant at about 12 volts, it was determined that the battery array was fully charged.

Computer Power Use Data Acquisition

Testing for the computer power use data acquisition setup was conducted for each piece of hardware individually. Each PC and monitor was connected to the Watts-Up-Pro power meter, and the power consumption in watts was measured over a period of 24 hours. For a standard PC and terminal server, loadtool.exe was run with the default settings. This allowed for the most realistic simulation of an actual computer in a computer lab environment. After the completion of each test, the data were pulled from the Watts-Up-Pro power meter. Power usage in watts was then exported into Microsoft Excel to be averaged in order to determine the power consumption over a 24-hour period. After retrieving the data from the meter, the memory was erased and the test was conducted for the next piece of hardware.

Data and Results

Alternative Energy Lab Energy Gathering Setup

The goal of this project was to determine the feasibility of using alternative energy to power a computer lab. To answer the question, the power generated by both the solar panel and wind turbine had to be calculated. The raw data for both alternative energy sources was exported from the digital multimeters into an Excel file to calculate the minimum, maximum, and average power generated. Table 1 summarizes the data.

Table 1. Power Profile for Solar and Wind

	Minimum Power (Watts)	Maximum Power (Watts)	Average Power (Watts)
Solar	-0.16142*	94.43	15.18
Wind	0**	365.34	179.44

*Power is drawn from the charge controller attached to the solar panel to power the LEDs and digital display.
**The wind turbine is idle, no power generated.

To calculate the power from the solar energy test, the formula used was P=VI. The calculation for wind power was twofold, due to the need for measuring two voltages and calculating the current. V=IR was used in determining the current. Once the calculation for average wattage was completed, the data could be extrapolated over the course of a year in kilowatt-hours (kWh). Table 2 illustrates that these data can then be computed to find the savings in dollars that the alternative energy sources produced, or would produce, in a given year, based on the data collected.

Table 2. Yearly Energy Data for Solar and Power

	Average Energy Produced per Year (kWh)	Average Savings from Alternative Energy per Year (Dollars)
Solar	132.98	20.62
Wind	1571.89	243.69

The calculation for converting watts to dollars is based on first converting watts to kilowatts and then using the cost of electricity from the utility company. The cost for electricity in the local city as provided by UPPCO was $0.15503 per kWh [7].

Computer Power Use Data Acquisition Setup

Table 3 gives the data for the power consumption of the computer devices, which were pulled from the Watts-Up-Pro power meter.

Table 3. Power Consumption of Computer Devices

	Average Power Usage (Watts)	Average kWh per Year (kWh)	Cost to run for 1 year at $0.15503 per kWh (Dollars)
Standard PC (Load)	117.974	1033.456	160.22
Standard PC (No Load)	105.251	921.998	142.94
Thin Client	15.346	134.439	20.84
LCD Monitor	44.137	386.642	59.94

The same calculations were used to compute the average kWh per device per year. However, in this case, the cost to run the device was calculated versus the energy savings. After calculating average power production for the wind turbine and solar panel, calculations could be made on the ratio of alternative energy sources to computer setup. This is done by adding the average kWh per year of each device and dividing it by the average energy produced in kWh of the alternative energy source. For example, it would take 0.9 wind turbines to continually power a PC at load with attached LCD monitor, based on data measured in Tables 1-3. If these data are further extrapolated over an average-sized computer lab of 30 standard PCs plus monitors, 27 wind turbines would be required. Table 4 summarizes the number of alternative energy sources needed to power each device continually. This is on a per-device basis, not a total for a computer lab.

Table 4. Number of Alternative Energy Sources to Power a Device

	Solar Panels	Wind Turbines
Standard PC (Load)	7.770	0.657
Standard PC (No Load)	6.930	0.587
Thin Client	1.011	0.086
LCD Monitor	2.908	0.250

In a real-world scenario, a computer lab would consist of approximately 30 computers and 30 monitors. Taking into consideration that these computers could be used on a daily basis, the following calculation can be made to determine the number of alternative energy sources required for a computer lab.

(PC-Load(0.657Wind Turbines) + LCD Monitor (0.250Wind Turbines)) * 30 = 27 Wind Turbines

(PC-Load(7.77Solar Panels) + LCD-Monitor(2.908Solar Panels)) * 30 = 320 Solar Panels

For a Thin Client computer lab, the numbers would be lower. Following the same calculations, the number of wind turbines and solar panels for a Thin Client lab would be 10 and 118, respectively.

Payback Period for Alternative Energy Lab Energy Gathering Setup

One of the major factors in determining the feasibility for an alternative energy lab is the initial cost of investment versus the time it would take for the savings to repay it. Tables 5 and 6 outline the payback period for a computer lab of 30 PCs for both wind and solar energy. The calculation shows the results with and without the cost of an energy storage system (batteries). The number of batteries was calculated based on the same setup in the testbed (one wind turbines and four batteries). There is no need to add additional energy storage batteries, as the excess electricity generated can be sold back to the power company for credit.

Table 5. Cost for Energy Units

Item	Cost Per Unit
10,000 Watt Power Inverter	$559.95
Wind Turbine	$499.99
Solar Panel	$484
Charge Controller	$90
Batteries	$104
PC	$500
Monitor	$150

Alternative energy sources do not directly provide a return on the investment but, instead, provide a reduced cost of operation by eliminating the cost of electricity. Using these savings as a cash flow, one can see that the potential payback for an alternative energy lab without an energy storage system would be estimated between five and six years. By adding the year with the last negative net cash flow to the remainder of the balance over cash flow of the next year, the payback period was calculated to be 5.10 years. Adding an energy storage system would add 1.7 years for payback. Figure 4 shows the payback period of the wind turbine. This method was also used to calculate the payback of a solar lab, which would be 30.41 years without an energy storage system.

Table 6. Payback Period of Alternative Energy Computer Lab

Year	Without Energy Storage System (Batteries)		With Energy Storage System (Batteries)	
	Cash Flow	Net Cash Flow	Cash Flow	Net Cash Flow
0	-33560	-33560	-44792	-44792
1	6580	-26980	6580	-38212
2	6580	-20400	6580	-31632
3	6580	-13820	6580	-25052
4	6580	-7240	6580	-18472
5	6580	-660	6580	-11892
6	6580	5920	6580	-5312
7	6580	12500	6580	1268

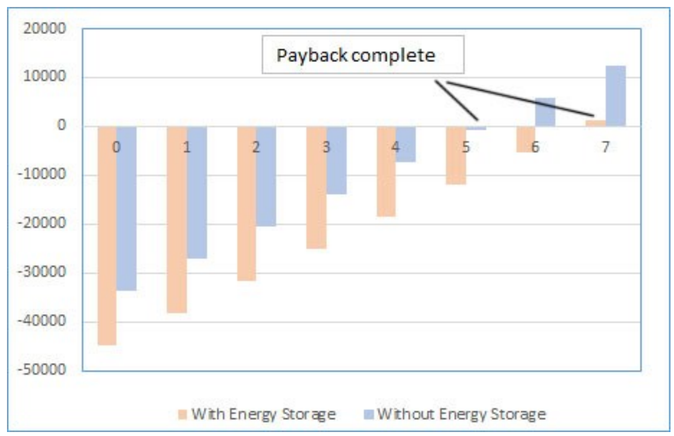

Figure 4. Payback Period of Computer Lab with Wind Turbines

Lessons Learned and Discussion of Results

With sufficient space and budget, an alternative energy powered computer lab could be a feasible venture. As the data provided by the lab setup on the DOW building show, the amount of energy produced by solar and wind generation methods is enough to power and sustain an alternative energy computer lab. Although scaling these sources provides enough electricity, the monetary investment will only be recuperated in a reasonable amount of time using wind power. Based on the calculation results, it may take too long for solar power to repay initial costs in the region where the authors reside (Northeastern United States). However, solar power should not be eliminated from the list of alternative energy sources. First, the price of solar panels has dropped 58% globally in the past five years, with an expectation to drop another 40-70 percent more by 2040 [8]. Second, solar panels can be used together with wind turbines to provide stable energy output on different weather conditions and season changes. Further testing could be conducted on varying sizes of solar panels and wind turbines to find the most cost-effective solution for an alternative energy setup.

The calculated result of 10-27 wind turbines or 118-320 solar panels to power a computer lab may raise some concerns on space constraint. The seemly large number can be attributed to the small-scale alternative energy power generation systems used in the test. For example, a 400-watt 12V wind turbine and a 130-watt 12V solar panel were used to generate energy in the current setup. The reasons for using such small power generation equipment include easy installation, easy management, and relatively low cost. There are many commercial-grade alternative energy power generators available on the market. For example, a 2000-watt wind turbine could potentially produce 5-6 times more energy than a 400-watt version does. It would only require 2-5 large wind turbines to power a computer lab. However, the installation of a 2000-watt wind turbine would typically require professional support. These wind turbines must be installed in a designated location that may be far from computer labs, thus adding additional costs for energy storage and transmission. Roof installation or on-campus installation for large wind turbines will not be allowed, given the university's safety rules. Therefore, it would require efforts by the university to build an array of commercial-grade wind turbines to power computer labs or classrooms.

The physical space required to set up an alternative energy lab would be based on the number of computers needed for the lab. Generally, wind turbines must be placed far enough apart as not to impede the flow of air around neighboring turbines. With 10-foot spacing for the 400-watt wind turbine used in the project, an area of approximately 1500-2000 square feet would be required. This would be the space of a rooftop for an ideal setup to avoid any obstructions like trees or neighboring buildings. However, installing 10-30 wind turbines in an area of 1500-2000 square feet on the roof of a building would raise many practical concerns, including safety, environmental, and maintenance issues. It is not a trivial task to apply for permission to install 20 wind turbines on the roof of a campus building, even for research and experimental purposes. All of the concerns mentioned above are legitimate and beyond the scope of this paper. The goal of this project was to determine the technical viability of using alternative energy to power a computer lab and provide a case study for people interested in the green technology field.

Additional tests should be conducted to correlate the wind speed and amount of sunlight on a daily basis. These data would make it easier to figure the feasibility of an alternative energy lab setup in other areas as well as predict the amount of energy that would be available based on weather conditions and seasonal changes. In performing data collection and analysis, it was noted that the estimates made were based off of a narrow time frame, primarily during the spring and the summer. For a more concise answer as to the feasibility of an alternative energy computer lab, and to the prospect of installing one at the authors' home institution, a larger data collection window must be used. If research is to be continued and ongoing, data must be collected over the course of at least one year to better estimate energy production from both the wind turbine and solar panel.

Green Technology on Campus

In addition to the alternative energy powered computer lab project, there are many other green technology-related research, education, and outreach activities at the authors' home institution. Most of these activities are managed and conducted by undergraduate and graduate students with guidance from faculty members. One of the largest endeavors is the Green Campus Enterprise. It is an option for graduation requiring two years of the student's involvement as an alternative for a senior design project. The Green Campus Enterprise is organized by self-motivating students working hard to make the university more sustainable in both low- and high-profile projects. Three such projects are described here.

The main goal of the Clean Air Cool Planet team is to measure the university's carbon emissions and analyze potential energy reduction projects. The information comes from energy use, agriculture, refrigerants, solid waste, commuting to and from campus, and data on air and vehicle travel involving the university. The information collected from this project will be entered into a carbon calculator to develop emission estimates for the six greenhouse gas emissions specified by the Kyoto Protocol and to identify the large sources of emissions on campus.

The overall goals of the Energy Savings Buildings team are to evaluate selected types of energy consumption in buildings on campus and develop potential reduction strategies. For example, a group of students is looking at the lighting in many different academic buildings across campus to see the cost the benefits of installing occupancy sensors and daylighting control. These sensors would be placed in areas such as classrooms, restrooms, labs, and some private offices. The group took the amount of hours the lights were on in an unoccupied room from a program to calculate potential cost savings with the sensors installed. After the calculations were made, the group would have to see what occupancy sensors would be the best or most effective for the rooms on campus. The second group evaluated the outdoor lighting around campus for potential conversion to LED lighting. The areas surrounding the university that were analyzed included Mt. Ripley, Tech Trails, and the campus street lights. The group wanted to see the payback times at the current level of illumination, and the payback times if an adjustable level of illumination on conditions like snow cover were to be incorporated into the LED lighting.

Another student self-managed endeavor on green technology is the senior design project. It is a two semester-long, team-oriented capstone course requiring the application of knowledge gained in previous courses. A sample project is the Universal Wireless Dynamic Power Monitoring project whose aim is to create a user-friendly implementation of using a modified power meter and being able to view these power meter readings from anywhere using an Apple iPhone / iPad. The modified power meters were a combination of a Kill-A-Watt power meter and a Tweet-A-Watt kit that included a transmitter and a receiver. Figure 5 shows the system architecture.

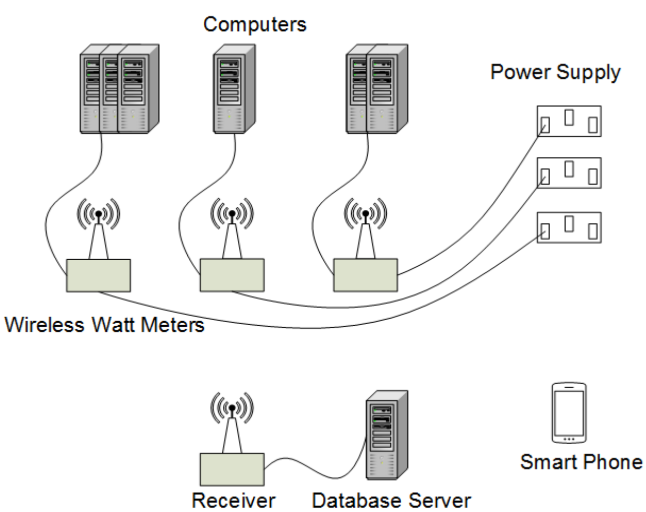

Figure 5. Wireless Energy Consumption Monitoring System

The transmitter was wired into a power meter to read data and transmit data wirelessly. The receiver was connected to a Linux server that ran a python script. This script was included in the Tweet-A-Watt kit and was modified to store the received data in a MySQL database. Apache web server and PHP scripts were installed on the Linux server to make the data accessible from any computer or mobile device. A user would be able to use the developed web application or the mobile app to select power meters and view power consumption data in real-time, both in a numeric format as well as in a graph. This project could be potentially used in many places. In the home and office, it could be used to check on the usage of devices, appliances, or even entire rooms. This could help in determining unnecessary expenses from either unused or inefficient devices / appliances.

Conclusions

For the Alternative Energy Powered Computer Lab project, the main focus was to study the technical feasibility of such a setup in a university setting. Budget, space, safety rules, and environmental impact are some of the main constraining factors. From a financial perspective, the monetary investment of wind power can be recuperated in 5-7 years, but solar power would take a much longer period to repay the initial costs of the system. However, the cost of solar power has dropped significantly in the past few years and will likely continue to drop. Therefore, solar power should not be eliminated from the candidate list of alternative energy sources. Space, safety, and environmental impact are some legitimate concerns for using alternative energy on a university campus. It would be relatively easy to install wind turbines or solar panels in a residential home or in a rural area. There are also other factors such as maintenance and opportunity costs. Considering all of these factors, it is not an easy decision to adopt alternative energy in a university setting for research and experimental purposes.

Meanwhile, students at the authors' home institution are working hard on many other green technology-related projects to push in the fight for going green and make a difference in the near future. New ideas and projects are being developed to help save energy and reduce carbon emissions. All these activities help students realize their social and environmental responsibilities and bring them together for a sustainable future.

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Biographies

YU CAI is an associate professor and program chair in the Computer Network and System Administration (CNSA) program in the School of Technology at Michigan Technological University. His current research interests include green computing, cybersecurity, and medical informatics. He is particularly interested in applying his research and techniques to real-life applications. He has been a consultant to many companies, including IBM and Ford. Dr. Cai serves on editorial boards of several international journals. He also serves on the program committees of many international conferences. Dr. Cai received his PhD in computer science from the University of Colorado at Colorado Springs in 2005. He is a member of IEEE and ACM. Dr. Cai may be reached at cai@mtu.edu

BRICE DOWNEY was an undergraduate student in the Computer Network and System Administration (CNSA) program in the School of Technology at Michigan Technological University. He was very interested in green computing technology and conducted the alternative energy powered computer lab project under Dr. Yu Cai's advising. Mr. Downley may be reached at bedowney@mtu.edu

MATTHEW SCHULTZ was an undergraduate student in the Computer Network and System Administration (CNSA) program in the School of Technology at Michigan Technological University. He participated in the alternative energy powered computer lab project. He may be reached at mhschult@mtu.edu

Effective Integration of Advanced Mobile Technology for Course Delivery in Information Technology Programs

Bilquis Ferdousi, Eastern Michigan University

Abstract

Integration of mobile technology is now inevitable in every sphere of life, including higher education. Mobile technology, which includes mobile devices and applications (apps), is a new instrument in changing traditional teaching and learning methods. This establishes a new area: mobile learning. Consequently, increasing numbers of higher education institutions are integrating emerging mobile technology as instructional tools for academic learning. Also, most students are from a generation that has grown up and is living in the world of mobile technology. Therefore, it is important for instructors to know how to keep up with the rapid growth of ever-changing mobile technology. Instructors need to know how to integrate emerging mobile technology in their classes.

Understanding the value of mobile technology in education can help university instructors and administrators to improve the instructional process, which, in turn, will lead to student academic success. In this paper, the author describes the effective integration of mobile technology into course delivery, focusing specifically on the types of mobile technology useful for information technology courses. Also addressed are the factors that affect adoption of mobile technology in the learning process to achieve effective learning for students.

Introduction

Advances in mobile technology are changing teaching and learning processes. Mobile technology is increasingly becoming a critical component in the educational environment and opening more opportunities for learners. Consequently, many higher education institutions (HEI) are utilizing mobile technology as an effective learning tool. The use of Internet-enabled mobile technology in learning offers students the opportunity to learn anytime and anywhere [1]. A number of mobile devices are available that can be valuable tools in course delivery to support student learning. Therefore, instructors need to be well informed and familiar with different available technologies and systems that are suitable for designing and delivering courses [2].

Mobile Learning

Recent developments in mobile and wireless networking technologies have removed time and space constraints in facilitating learning. The promising paradigm of mobile technology embeds the learning process into the everyday life environment. Consequently, the term "mobile learning," or m-learning, is starting to appear in educational environments: "The world is becoming a mobigital virtual space where learning and teaching digitally is possible anywhere and anytime" [3]. Today, when timely access to information is vital, mobile devices such as laptops, tablets, phablets, smart phones, iPods, digital cameras, personal digital assistances (PDA), e-readers, etc. have become common devices used by the younger generation, especially by college students. Mobile devices with software applications connected to wireless networks, such as 3G, 4G, Wi-Fi, Bluetooth, etc., provide students with access to learning resources, allowing them to work on course materials and interact with instructors as well as other students.

In scholarly literature, m-learning is defined as an extension of e-learning, which is performed using portable mobile devices such as laptops, iPads, PDAs, smart phones, etc. However, m-learning is anytime/anywhere seamless learning that represents more than a mere extension of traditional learning or e-learning. A common definition of mobile learning is the use of portable devices with Internet connections in educational contexts. Mobile technologies support formal and informal educational environments, allowing unique learning experiences for students [4]. Mobile learning has some unique characteristics that include portability, wireless networking connectivity, and ubiquity. The most important characteristic of mobile learning is ubiquity, referring to its ability to materialize whenever and wherever needed using handheld devices [3]. Ubiquity is more than just being mobile and refers to "the interconnectedness of the mobile device with its environment and other devices," allowing learning continuity in any situation [4]. Mobile technology provides ubiquitous learning spaces and experiences across different situations or contexts [5]. Thus, mobile learning can be defined as a personal, unobtrusive, spontaneous, anytime, anywhere method of learning that allows learners continuous access to educational materials [6].

Mobile learning happens when a learner is not in a fixed, predetermined location and learns by taking the advantage offered by mobile technology [7]. Thus, the term "mobile learning" refers to the learning that takes place in multiple locations, across multiple times using wireless portable devices such as laptops, PDAs, tablets, e-readers, smart phones, etc. [8]. Mobile learning is not just the simple extension of e-learning, as suggested by some researchers. The transformation of e-learning into m-learning (see Figure 1) requires consideration of some issues during the design and development of course content [9].

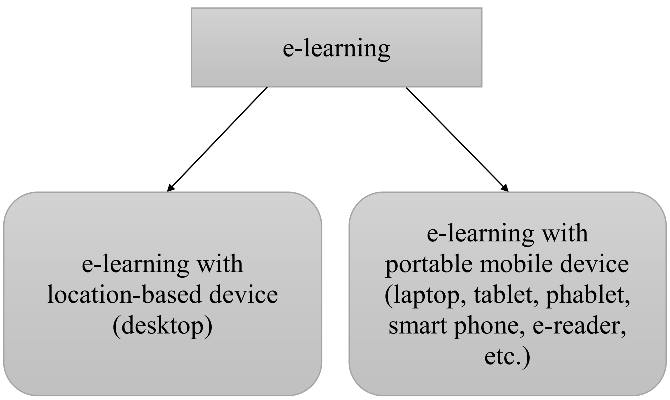


Figure 1. e-Learning Transforms to m-Learning

Mobile Technology as Learning Tools

In mobile learning, course content is delivered using portable and handheld devices with a set of applications with similar functionalities [10]. The idea of learning through mobile devices has gradually become a trend in the e-learning environment, as mobile devices are becoming more capable of performing the functions necessary in academic learning [3, 11]. Figure 1 lists a number of different Web-enabled mobile technology devices used for academic learning purposes, and software applications such as Web 2.0, cloud computing, blogs, wikis, and social media are being used as tools in mobile learning environments [12].

Architecture of Mobile Learning Systems

The structural design of a mobile learning system is based on client-server network architecture, where mobile devices with wireless network connections are clients that have access to course content stored on a server. Students can learn anywhere and anytime using mobile devices connected to the server through middleware architecture. Within this type of architecture, the server stores learning management systems (LMS) with course content and other learning resources [13], all downloadable as per the learner's request.

The middleware architecture supports basic frameworks for student learning, allowing transmission of different course content such as graphics, text, images, voice, etc. between server and client. Mobile learning systems are designed to support applications on a variety of platforms in different types of mobile devices communicating in a global environment. Therefore, to implement a mobile learning system that properly supports the educational goal of running multimedia and streaming files, a learner-centered course design approach requires the design of application software that is compatible with the middleware architecture configuration (see Table 1) [13].

Table 1. Mobile Technology as a Tool for Mobile Learning

Mobile Technology	
Hardware	Software
Server-side (Stores course content and other learning resources)	*Mobile Operating Systems* *Middleware*
Client-side *Mobile devices*: Laptop, Netbook, e-reader (Kindle, Nook, etc.), tablet (iPad), phablet, smart phone (iPhone, Android, Windows), PDA, etc.	*Application Software* *Learning management systems*: Blackboard, Canvas, Angel, SAM, Connect, etc. *Digital apps*: Web 2.0, Cloud computing, blogs, wikis, Google drive, podcast, screencast, voice thread, social media, etc.

Mobile Devices and Operating Systems

Different sizes of mobile devices with different types of network communication services are being used in mobile learning [11, 13]. The most popular are laptops, tablets, phablets, and smartphones. There are five main tablet manufacturers: Apple, Samsung, Motorola, HP, and Blackberry. Manufacturers develop their tablets with a specific set of hardware configured with special characteristics to offer optimal features to their users [14]. A phablet is a mobile device designed to combine or straddle the size and format of smartphone and tablet. Like any regular computer operating system, a mobile operating system is the software platform in a portable handheld mobile device that other applications run on top of. The mobile manufacturer selects the mobile operating systems for a specific device, and the mobile operating systems control the basic functions and features available. These systems also determine which third-party applications can be used on a specific mobile device, as a multitude of applications are available [14]. Some of the most common and well-known mobile operating systems include iOS, Android, and Windows. iOS is a mobile operating system developed by Apple Inc., used as the default operating system for iPhone, iPad, and iPod. iOS is a basic version of Mac OS, a UNIX-like operating system [14].

The Linux-based Android is an open-source mobile operating system and an application framework supported by Google. "The Java programming language forms the core of the entire Android OS" [14]. The OS provides an open development platform that allow developers to create applications for its device. According to Pereira and Rodrigues [14], "The operating system for Windows phone was developed using Microsoft's .NET framework. Applications written in any of the .NET languages compile to a common byte code that runs over the .NET virtual machine....Programs written for one Windows mobile device work on any mobile device running the same version of the operating system."

Mobile Applications

The mobile application is software in mobile devices that provides a mobile platform for students in learning. The mobile learning applications, which include streaming video and audio, can support visualized learning processes, class discussion, lectures, tests, quizzes, assignments instructions, and grades. To access learning content on a mobile device, the application must be downloaded to the device. Numerous useful mobile applications are available to integrate into the learning process. Following are a few examples:

<u>Web 2.0</u>. Emerging in the mid-1990s, Web1.0 immensely expanded access to information and started the open educational resources movement in education. Later, Web 2.0 created a more far-reaching revolution in information access. Web 2.0 tools such as blogs, wikis, social media, tagging systems, mashups, and content-sharing sites are examples of user-centric information infrastructure. Web 2.0 facilitates innovative explorations and experimentation and emphasizes interactive participation and understanding.

<u>Blog or Web log</u>. A digital tool blog or "Web log" can be used in class to capture and disseminate student- and instructor-generated course content and knowledge. Students often learn as much from each other as from the instructor or textbook. Since blogs offer peer-to-peer knowledge sharing on the blog platform, it can be used to promote dialogue in learning disciplines allowing students to express their opinions. Farmer et al. [15] suggested that "blogging is a useful practice for the development of higher learning skills, active, learner centered pedagogy, authentic learning, associative thinking, and interactive learning communities."

<u>Social media</u>. Increasingly, social media are becoming important learning tools that enable students to interact, learn, and engage in class. Social media that can be used for academic learning and instruction purposes include YouTube, LinkedIn, Facebook, and Twitter.

Evaluation Criteria to Select Mobile Tools in Course Delivery

A growing number of instructors and students are adopting mobile devices and using applications without formal guidelines to evaluate the apps' effectiveness for their course. Any instructional strategy can be supported by a number of contrasting technologies; similarly, any given technology can support different instructional strategies of different courses. However, some are more appropriate than others for a given course. Therefore, before deciding which tool to use in a class, a set of evaluation criteria are necessary [16]. The literature suggests the following relevant criteria to evaluate mobile tools [17]—accessibility, usability, performance, relevancy, creativity and collaboration, privacy and intellectual property, durability, and cost.

The tool is compatible with Windows and/or Mac and accessible by different Web browsers such as Internet Explorer, Google Chrome, Mozilla Firefox, etc. Also, the credibility of the app developers is important. The tool is easy to use with the Help link. The design of the tool is user-friendly and simple to install. No third party software is required. The tool also makes it easy to track student class assignment activities. The tool is embeddable into the class LMS. It can be customized or extended to fulfill class requirements. The tool must be relevant to the course content to ensure effective learning. Also, the text, visual, and audio content of the tool should be at the appropriate level for the course.

The tool must allow opportunities for different types of interaction (visual, verbal, and written) among students and instructors. The tool increases the perception of connectedness and encourages collaborative learning. The tool keeps information private, and especially protects student personal data. The tool allows instructors and students to retain their intellectual property rights or copyright of the course content they create. The tool will be around for a while, not be changed or obsolete in the near future in the fast-changing technology world. The tool should be affordable to students, either free or a minimum cost for purchase and/or update. Expensive tools will be an extra burden on students.

Integration of Mobile Technology in the Delivery of Information Technology Courses

Computer lab assignments are fundamental aspects of student learning objectives in information technology programs. In most of the computer networking courses in such programs, hands-on lab exercises tend to be very specific and require operating system configuration in computer devices and changes in the local area network. This requirement needs privileged access into specific and exclusive computer labs. HEIs provide many computer lab facilities with desktop computers, but students have limited access, because most of those labs are reserved for teaching classes and are usually unavailable or not always available to students for hands-on class assignments. This limited access makes it impractical, if not impossible, for students to complete complex hands-on lab exercises that require extra time beyond their class period in exclusive computer labs.

However, most students now regularly carry and extensively use their Web-enabled mobile devices [8]. With increasingly improved hardware, software, networking infrastructure, and systems for mobile technology and decreased costs, mobile technology is becoming more affordable and sustainable in learning [7]. As mobile technology becomes better, faster, and cheaper, and HEI continuously struggle to reduce the expense associated with exclusive computer labs, learning management systems (LMS), virtual machine, and cloud computing can be alternatives needed in IT courses [18].

Virtualization

Recent progress in computer networking provides an opportunity to build "unit sharing virtual environment for teaching and learning" in higher education [18]. Therefore, the issue of exclusive computer labs for courses such as computer networking, systems administrations, and operating systems in IT programs can be lessened by use of virtualization. Virtual machine technology allows each student to build his/her own virtual computer network, as required by lab exercise assignments, without interfering with the physical structure of the computer lab, and thus not disturbing other activities running in the lab. Virtualization is a combination of hardware and software architecture that creates virtual machines, allowing a single physical machine to act as several machines. Recent advances in virtual machine technology create growing interest in using it as an important tool in the design and development of courses such as computer networking, operating systems, and server administration in information technology programs. Virtualization allows students to install the virtual machine on their laptops and work on their lab exercises from anywhere and at any time without accessing the lab.

Cloud as Platform

With the rapid growth of wireless networking, mobile technology, and cloud computing, cloud-based mobile learning has become a potential method in education (see Figure 2) [19]. Due to its ability to provide computation and storage resources as services, the cloud is a promising infrastructure that can add great value to mobile learning. The main advantage of cloud computing is the flexibility it offers to create, share, save, and collaborate course content from anywhere and at any time [18].

The common characteristics of cloud computing are on-demand scalability of regularly available and reliable computing resources and secure access to data and services from nearly anywhere inside or outside the campus [20]. Because of cloud computing, more and more complex applications such as word processors, spreadsheets, multimedia presentations, and database are now delivered as services over the Internet on a scalable infrastructure. All those applications are accessible from mobile devices, while the files are in the cloud. This enables students in information technology courses, such as computer applications, to work on their homework assignments using mobile technology. They do not need to install content management systems, such as SAM or Connect, onto their mobile devices, as those systems are stored on the cloud server. As clouds enable wider accessibility to any learning platform with an Internet connection, instructors and students now have better access to a learning platform from anywhere and at any time [21]. Thus, by using cloud computing, HEIs can "provide students free or low-cost alternatives to expensive" learning tools [22].

Benefits of Using Mobile Technology in the Learning Process

Previous studies on mobile learning suggest various benefits of using mobile technology, such as "personalization, course context sensitivity, ubiquity and pedagogy" [4]. One of the strongest arguments in favor of mobile technology is the mobility or accessibility from anywhere and at any time. Mobile technology facilitates mobile learning that enables learners and instructors to extend learning beyond traditional location-based classroom and computer labs and provides increased flexibility with interactive opportunities. Mobile technology-based course delivery, or mobile learning, provides: 1) anytime and anywhere access to learning content,

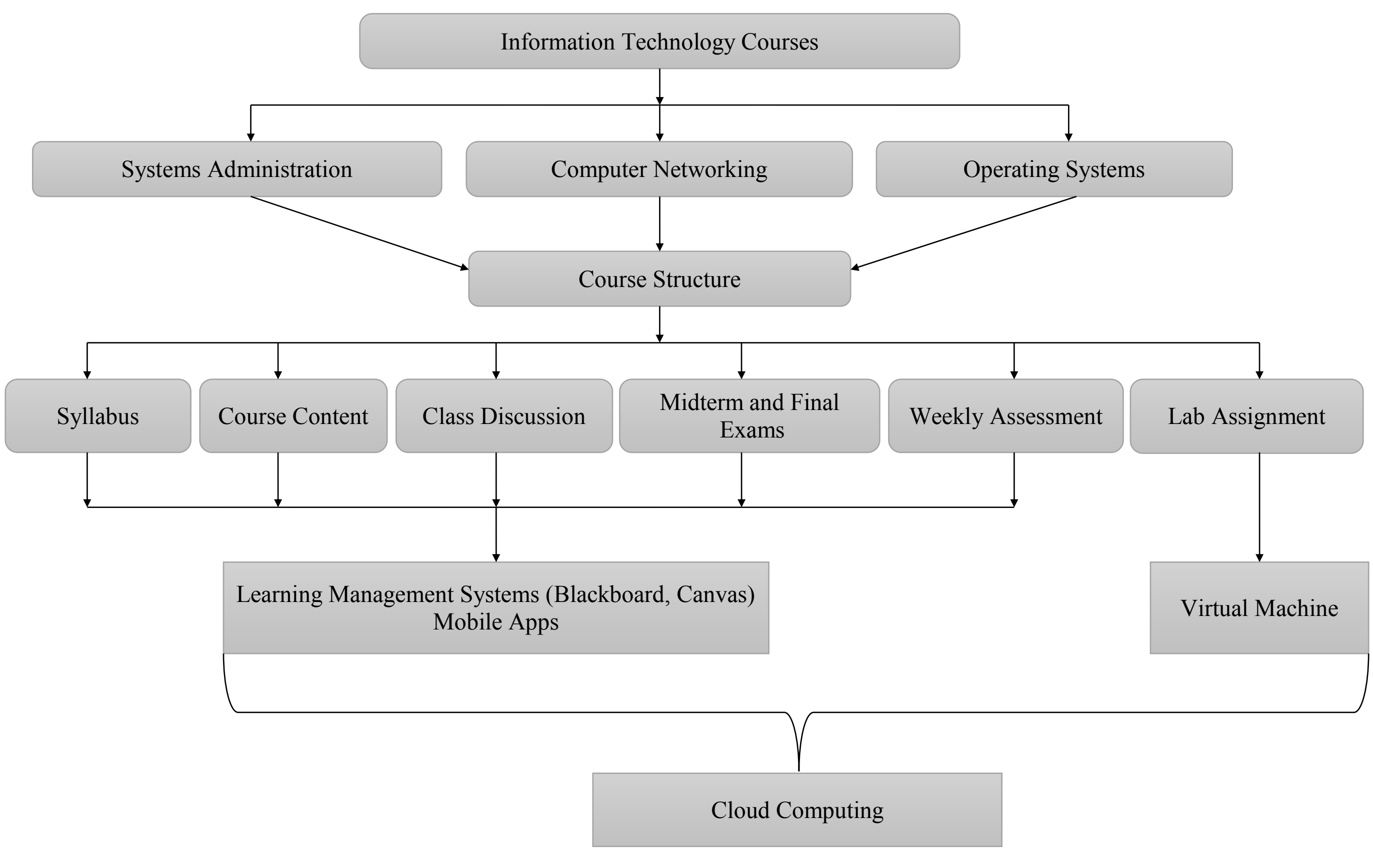
2) enhanced student-centered situated learning, 3) just-in-time learning or review of course content, 4) differentiated and personalized learning, and 5) collaborative learning processes that enhance interaction between students and instructors [4, 8]. Mobile technology can impact learning outcomes by improving access to course content, while maintaining the quality of education. Using mobile technology in learning can also ensure immediate feedback that provides continued motivation for those students not otherwise motivated by traditional learning methods.

Challenges of Using Mobile Technology in the Learning Process

The benefits of using mobile technology in learning do not come without challenges. There are some unique problems in mobile learning caused by the limitations of mobile hardware and wireless networks [6]. Learners may not be inclined to completely accept mobile learning unless those limitations are properly addressed. The restrictions or limitations found in using mobile technology in learning are listed here [6, 23-25].

- The most pronounced limitation is the small screen size with its poor resolution, color, and contrast of the mobile tools that makes the learning activity challenging for some students. The tiny screens and small keyboards in mobile devices cause text-input difficulties.
- With rapid proliferation of mobile applications, there is a wide variety of mobile devices with different characteristics, but not all mobile applications are adaptable to all different mobile devices. This lack of standardization and the issue of software interoperability also causes challenges in mobile learning.
- Mobile devices have technical limitations, such as small memories, short battery life, and limited computation capabilities. Limited battery life of mobile devices can be a serious issue in learning from anywhere and at any time. Also, low storage capacity in mobile devices will not allow students to store or even download large course files.
- Low bandwidth and limited processor speed can slow down the overall learning process.

Figure 2. Integration of Mobile Technology in Course Delivery



Conclusions

Mobile technology is increasingly being used to facilitate learning with new real-world approaches [14]. This method of learning is called mobile learning and refers to learning using mobile and handheld devices with wireless network connections. Mobile technology is changing learning processes by enhancing 24/7 access to course materials, just-in-time information sharing, continuous interaction, and collaboration among learners and instructors. Thus, mobile technology can be a successful tool in involving students in effective pedagogical activities anywhere and at any time. Mobile technology brings new opportunities into the learning environment with its unique feature of mobility, which offers learners freedom and self-regulation in their learning process. However, along with all of the benefits, some drawbacks may impede the adoption of mobile technology in learning. Some technical limitations can challenge the delivery of courses. Screen size, processing power, device compatibility, storage capacity, etc. are the issues in using mobile technology in learning. Also, student preparedness for using mobile technology for their entire learning process has not yet been fully explored.

Therefore, the factors affecting the use of mobile technology in learning need consideration in course delivery. The main criteria are the constraints and quality of services of mobile devices and applications. To make mobile technology-enhanced learning or mobile learning an effective delivery method that meets course objectives, the constraints of mobile technology need to be addressed during course design. Institutional support is also necessary for training faculty and staff in designing courses in mobile formats and for providing technical support. Finally, some content related to e-learning systems are not yet suitable for mobile devices. Software developers, learning application designers, and practitioners need to address this issue during their software design and development.

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Biography

BILQUIS FERDOUSI is an assistant professor of information assurance in the School of Information Security and Applied Computing at Eastern Michigan University. She has over 15 years' of experience as a full-time faculty member in information technology and information systems. Her research interests include cloud computing, cryptography and social engineering in cyber security, mobile application and digital technology for interactive learning, human factors in technology acceptance, and gender gaps in STEM programs. Dr. Ferdousi may be reached at bferdous@emich.edu

American Reshoring: A Model for Italian Economic Development

Patricia Polastri, Texas A&M University-Kingsville; Antonella Viggiano, Luis Guido Carli University

Abstract

The United States has been a frontrunner in offshoring and outsourcing initiatives over the past two decades, seeking to obtain a competitive advantage in the manufacturing and service industries. But due to offshoring, unemployment rates soared. The promise of low-cost countries has not materialized, and the costs of producing goods abroad has substantially increased. After several years of experience and a greater understanding of offshoring, many American companies have decided to reshore. Local governments are providing incentives to companies to stimulate the re-birth of American manufacturing with the potential to reduce unemployment rates and the growing trade deficit. Italy is experiencing a similar situation. However, Italian companies are still sluggish in their reshoring efforts and there is not much evidence of any concerted effort from the government to enact policies that may attract the companies that offshored. The purpose of this study was to provide an analysis of the strategies used by the U.S. government promoting reshoring that could be adapted to the Italian market and its current situation.

Introduction

Globalization and the disappearance of borders between countries is affecting the way we do business and in particular the internal organization of companies [1]. Over the past decades, the world has witnessed the birth of a new economic order, the reorganization of financial systems and the growth of new economic powers such as China and India. These emerging economies are reaching a more dominant position in the global economic arena and they have been the principal target of offshoring [2]. However, offshoring is not a new phenomenon. In 1911, the Ford Motor company moved its assembly operations to Traffor Park, England, seeking to reduce transportation costs and better supply the European market [3].

The first companies to participate in offshoring have been multinational enterprises trying to adapt their structures and strategies to diverse cultures, frequently with poor results [4]. Today, the advanced stage of market globalization and the advent of communication tools, such as the Internet, allow small and medium enterprises to build a market strategy and to succeed in market niches that are distant and unknown. According to Manning et al. [5], the terms outsourcing and offshoring are often used interchangeably but, in fact, the two concepts refer to two different strategies implemented by companies. Outsourcing refers to the physical boundaries of the enterprise, as it consists of a practice that granted the creation of products and/or services to a third party (domestic or offshore). Offshoring, instead, refers to the process of sourcing any business function supporting domestic or global operation from abroad, in particular from low-cost emerging economies, either through a wholly owned subsidiary or a third-part provider.

In the offshoring process of manufacturing and services activities, the selection of location is a key factor. Among the multiple dimensions taken into account by companies in their offshoring considerations, location and total labor costs seem to be the most relevant. Thereafter, companies look at the flexibility of the labor market, the characteristics of industrial relations, the availability of incentives/benefits provided by the governments, and the physical infrastructure and transportation efficiency of the country. Despite the many benefits of offshoring, any strategic decision as significant as this presents risks such as lack of flexibility, hidden costs, quality, loss of control, loss of Know-How, and customer dissatisfaction. In the past few years, however, the most important risks have been of economic character. According to Sirkin et al. [6], there has been a large reduction in total production cost differential between Western and Asian countries, primarily due to the increase in labor costs experienced in developing countries. In China's case, the rise of labor costs has steadily increased at a rate of 10 to 20 percent per year, while in most Western countries the rise has only been of about 2 to 3 percent for the same period.

The Boston Consulting Group [7] identified additional forces that have reshaped the map of international competition between 2004 and 2014, prompting companies to re-evaluate their location choices. Among these forces are exchange rate variations, labor productivity (which increased by more than 50 percent in some Western countries) and the declining cost of energy in the U.S. Economic and political stability are other factors currently receiving greater attention in the selection of host countries. All of these factors have, over the years, reduced the comparative advantage of developing countries and given rise to a new phase of relocation strategies.

Over the years, developed countries have seen a decline in the weight of manufacturing on the economy. In the U.S., value-added manufacturing declined from 17 to 12 percent from 1997 to 2012. In Europe, the value generated by the manufacturing industry decreased from 18.5 to 15.1 percent between 2000 and 2013. This decline resulted in the loss of almost 10 million jobs. Manufacturing is a key component for European development, since it represents 74.7 percent of exports, 63.8 percent of R&D, and 60 percent of productivity growth [8]. In Italy, the decline was from 20 to 15 percent. The UK experienced a decline from 18 to 11 percent, while Germany declined to 23 percent [9]. A country's wealth depends heavily on its manufacturing sector. The decline of the manufacturing sector in the developed world has a negative impact on the service sector as well, affecting the entire economy of the region. In addition, the manufacturing industry favors a fundamental part of innovation activities, which lead to overall productivity growth and, therefore, to real income growth [10].

The authors of this current study define reshoring as the opposite decision of an offshoring strategy and that it is "the shift of production to the country of residence of the parent company" [11]. It should be noted that, depending on the return procedure, other definitions exist for the process of reshoring, but they were not be part of this analysis. Reshoring is not a new phenomenon, but has accelerated in recent years, due mainly to economic changes in the host countries usually located in the developing world. Reshoring should not be understood as a phenomenon contrary to offshoring. The fact that some companies decide to return to their home countries does not imply that offshoring has been supplanted by reshoring. The two phenomena are independent from one another, because they concern industries and companies at different stages in their lifecycles using different strategies to be more competitive on the markets they serve. Many other critical variables have been identified (other than labor cost and labor flexibility) as relevant for offshoring. These are excellence in quality, branding, flexibility, speed in responding to customer/market needs, and attention to ethics in the production process [12].

Manufacturing and Reshoring

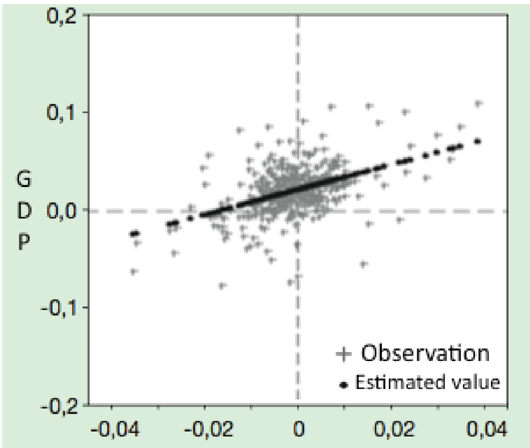
The manufacturing industry is in a period of profound transformation, accompanied by uncertainty and resistance in dealing with necessary cultural changes induced by new technologies, unstoppable expansion of the service sector, and the integration of global markets [13]. This is even more evident in the Italian market, where the most valuable feature is the "Made-in-Italy" worldwide recognition. Customers associate a higher value to the goods manufactured in their country of origin, and Italy has already gained recognition for many of its manufactured goods [14].

In Italy, inadequate fiscal policies have contributed to the offshoring of the Italian manufacturing industry to low-cost production areas [15]. According to a 2013 study conducted by Confindustria [17], (the main Italian association representing the manufacturing and service industries), there is a positive relationship between higher manufacturing intensity and economic growth. According to CSC (Centro Studi Confindustria), the manufacturing industry is essential for economic development. The theoretical reason for the dynamic role of manufacturing as the engine of growth, expressed by Kaldor [16], is in the very nature of the processing industry: manufacturing generates innovation demand. According to Confindustria, higher demand for manufactured goods stimulates an increasing specialization of the same manufacture, and allows for the generation of a growing disposable income in the economy. This additional income turns into further increased demand for manufactured goods and creates a vicious cycle process in which increased industrialization due to stronger and higher economic growth stimulate more industrialization [17]. The phenomenon, however, is not predictable. With the increase in disposable income, consumer demand tends to move away from increasing amounts of manufactured goods to increased demand for services leading in this way to slow the overall growth of the economy [16].

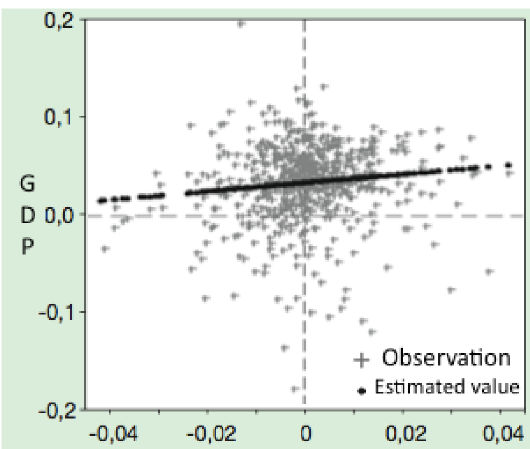
To test the effect of manufacturing on economic growth, the CSC (see Figure 1) estimated the relationship between the annual change in GDP and the corresponding annual change in the manufacturing share of the total economy, expressed in real terms. It was noted that a point increase in the share of manufacturing (in real terms) resulted in a GDP increase of about 1.5 percentage points for the developed world, while only 0.5 for the developing world. No wonder the multiplier effect of manufacturing remains strong compared to any other sector.

Reshoring in the U.S.

The Reshoring Initiative, a U.S. organization that monitors the reshoring phenomenon, has recorded 357 cases of American companies reshoring. Their records show that by reshoring over 39,530 jobs have been created [18]. The Reshoring Initiative states that companies producing electrical appliances, textiles and clothing, metal products, and transportation account for almost 50 percent of the companies returning home. The organization mentions that labor costs are not the only nor the main motivation factor determining the return of these companies. In the U.S., labor costs have remained broadly unchanged since 2000, while in China they have quadrupled, they note. U.S. companies are returning to America mainly thanks to incentives, the possibility of finding a qualified workforce, and, more importantly, due to the value of what “Made in America” represents.



(a) Developed Countries



(b) Developing and Emerging Countries

Figure 1. CSC Elaborations on Global Insight Data

A significant example of the return of the manufacturing industry to the U.S. is represented by the manufacturing giant Whirlpool, as stated by Selko [19]. In 2013, Whirlpool decided to reshore from Mexico and started producing washing machines for the American market in the U.S. again. The reason for their return was mainly to respond faster to changes in demand. Another example is provided in the automobile industry [19]. The Ford Motor company has invested $1.6 billion on its U.S. facilities and is expecting to create 12,000 new jobs by 2015. Ford has already brought home some of its production from countries like Japan, Mexico, and India. U.S. multinationals have been influenced by the generous incentive packages provided not only by the federal government but also by small local governments [20].

Reshoring in Europe

The data processed from the Uni-CLUB MoRe Back-reshoring project [21] indicated that, in 2013, 145 instances of reshoring involved European companies. The instances were mainly related to Italian companies (60 cases), Germany (39 cases), and France and England (20 cases each). Additional evidence of the advancement of reshoring is arising from the survey conducted by the Fraunhofer Institute for Systems and Innovation Research (ISI). The study comprised 3293 companies from 11 European countries (Austria, Switzerland, Germany, Denmark, Spain, France, Croatia, Portugal, Netherlands, Sweden, and Slovenia). Compared to the factors motivating American companies to reshore, European companies are reshoring mainly to improve product quality, achieve greater production flexibility, and provide faster responses to changes in demand, while offering more expedient product customization [22]. However, for any business that has reshored to its home country, about three companies have offshored. Consequently, unless Europe does not launch specific measures to encourage reshoring, reshoring will not be sufficient to significantly aid in the revitalization of the European manufacturing industry [10].

Reshoring in Italy

Italian companies are now rethinking their selection of Eastern Europe and Southeast Asian countries, where they offshored in order to reduce costs and gain some competitive advantage [17]. Italian companies are re-discovering the strength of the “Made in Italy” slogan for industrial activities. China has experienced a reduction in Italian manufacturing on its territory, after being the main destination for Italian manufacturing. Table 1 lists a number of other countries that have seen a diminishing Italian presence.

Table 1. Countries Seeing a Diminishing Italian Presence

Italy’s reshoring	Occurrences
China	21
Eastern Europe	19
Western Europe	10
North America	2

In Italy, the reshoring effort seems to be favored by some location advantages related to the availability of productive excellence [23]. In particular, preference is given to locations where local suppliers provide a comparative advantage in terms of high levels of flexibility and reliability in production, higher value-added functions, innovative capacity, and cost competitiveness.

Reshoring Strategies in the U.S.

Incentives and policy strategies are complementary. In the short term, incentives entice companies to reshore, while, in the long term, the development of synergies in terms of innovation ensures the continuation of local advantages, which consolidate and strengthen the presence of reshored companies in their home territories. In the U.S., several strategies are being implemented at the Federal and State levels. At present, there are several Federal programs supporting and strengthening the U.S. manufacturing industry [19]. These programs range from tax benefits to incentives for technological innovation, and support for training the workforce, including support for some exports. In 2012, the Obama administration launched the "Blueprint for an America Built to Last" act, which was a multi-sectorial intervention package.

The purpose of this act was to create new manufacturing jobs on U.S. soil, while discouraging offshoring through tax incentives, tapping synergies among universities and industry, research centers and business, and reducing the cost of energy. Another initiative launched during the Obama administration was the "Make it in America Challenge," urging U.S. companies to maintain, expand, and/or bring home their manufacturing. Subsequently, these efforts were intended to accelerate the creation of jobs, while inducing foreign companies to implement business investments in the U.S. [24].

The Department of Commerce offers the Assess Costs Everywhere (ACE) tool, which can be used by companies to calculate their total costs and evaluate the profitability of a reshoring decision [25]. Another resource developed by the University of Michigan and funded by the Economic Development Administration (EDA) is the National Excess Manufacturing Capacity Catalog (NEXCAP) [26]. This catalog outlines unused production sites, provides data regarding specialized workers, local infrastructure, and other information that can help companies make manufacturing location decisions. The EDA [27] also provides the U.S. "Cluster Mapping Project" that includes information about the business environment of individual American States. It provides state performance, demographics, and geography, as well as a platform for debate about best practices in the field of economic development, innovation, and policy. Another example of incentives favoring reshoring is the National Network for Manufacturing Innovation (NNMI) [27]. This network provides solutions to manufacturing problems related to innovation, thanks to collaborative research between industry and academia. The goal is to create and develop new skills and/or innovative production processes, seeking to accelerate the commercialization of products in order to boost American companies' competitiveness on the global market [28].

Individual states are developing strategies to make their areas more attractive to companies considering reshoring. The state of Pennsylvania launched the "PA Made Again" initiative, with the purpose of creating new jobs through the preservation and expansion of the manufacturing sector [30]. The state of Mississippi, together with Mississippi State University, intended to strengthen the existing supply chains of its manufacturing sector, especially in the areas of automotive and furniture manufacturing. The initiative was expected to create jobs, improve professional training, promote exports, and attract direct foreign investment. Finally, the "Select SC" program, launched by Clemson University in South Carolina, focused on improving in-sourcing, development, and direct foreign investment [29].

And it is not just manufacturing companies that are adopting measures to reshore. After decades of supplying the American market with low-cost goods from China and Asia, retailers such as Walmart have rediscovered the value of "Made in the USA." Thus, Walmart has invited more than 500 American manufacturers to their headquarters in Bentonville, AR, with the intention of signing collaboration agreements. The goal is to reposition products manufactured on American soil on the shelves of their North American stores [28]. In 2010, the "Reshoring Initiative" [30] was born in Illinois, with the goal to educate all interested audiences about how to bring back the manufacturing industry they once lost. The founder and president, Harry Moser, is adamant in his quest to promote the "Total Cost of Ownership" tool to all those considering offshoring. The TCO tool provides insight about many hidden costs, usually overlooked when comparing the cost of domestic to foreign manufacturing. The TCO tool also shows the value of having products manufactured in America, not only from a cost perspective but also from the often-neglected environmental perspective.

Reshoring Strategies in Europe

European policies in support of reshoring are not as developed as those implemented in the U.S. In order to revamp the declining manufacturing sector in Europe, the

European Union is trying to provide new incentives to the manufacturing sector. These incentives have not yet been translated into actual industrial policies [31]. In Europe, reshoring is implemented independently, and at will, by each independent member state. The United Kingdom is the principal country to embrace policies that promote reshoring. The tools used by the British government are legislative simplification, flexibility of the labor market, tax reduction on workers and companies, legislation to exempt foreign dividends of the resident enterprises from local taxes, and to provide low-cost energy for both traditional and renewable sources over an extended period of time [32]. In addition, the British government participates in the financing of the "Advanced Manufacturing Supply Chain Initiative" (AMSCI), a competition aimed at improving the competitiveness of British supply chains to encourage suppliers to relocate their manufacturing to the UK [33].

France is among the best examples in attracting investment, thanks to various factors such as the best tax deduction in Europe for research and innovation. They also provide a reduction of 15 percent on corporate income tax; attractive tax incentives for financial companies and headquarters; exemptions for dividends received from subsidiaries; and, interest deduction on acquisition costs of subsidiaries or assets. The French Ministry for Industrial Renewal has also developed the Colbert 2.0 tool, inspired by the American Reshoring Initiative tool, sharing the same goal of assisting companies to assess their own reshoring operations [34]. In 2013, the Dutch government created a special fund of 600 million Euro to support reshoring. The NFIA (Netherlands Foreign Investment Agency) assists companies in finding concessions and locations. The Netherlands has a competitive position, thanks to a reduced domestic delivery time, highly qualified workforce, and automation policies that reduce the burden of labor costs on final products [32].

In Germany, reshoring is indirectly supported by policies that increase location advantages and build sophisticated competitive advantages for their entire system. Over the past few decades, unlike other European countries, Germany did not passively witness the de-industrialization and dismantling of its manufacturing sector. On the contrary, the German government has always recognized that, in order to maintain their advanced economy and welfare system, they need to preserve their dynamic and highly specialized manufacturing industry. With this in mind, two different strategies were implemented: the "High-tech Strategy for Germany," and the "Germany as a Competitive Industrial Nation." Both strategies aim to support innovation, promote technology transfer, increase the skills of the workforce, and promote interaction between manufacturing and the service industry [35].

Reshoring Strategies in Italy

In Italy, the reshoring phenomenon has not yet reached the proportions observed in the U.S., where it is favored by industrial incentives and low-cost energy. Nevertheless, it is experiencing a growing trend. Unlike what has been discussed about the U.S., the reshoring of manufacturing to Italy is the result of an almost spontaneous belief rather than an industrial policy. Reshoring is affecting sectors such as textiles and clothing, mechanics, as well as the pharmaceutical, biomedical, and transportation industries. Companies reshoring are locating in all regions of the country and the majority are reported to be producing high-end manufactured goods, where quality is associated with the renowned "Made in Italy" slogan, such as in fashion, clothing, footwear, furniture, and automotive industries [36].

According to KMPG, Made in Italy is a strong and worldwide recognized brand, an intangible heritage shared by Italian businesses; however, this advantage seems to lack the recognition and support it deserves from the Italian government. Made in Italy succeeds thanks to the commitment of individual companies and entrepreneurs. Institutions and politicians unconsciously reduce this unique advantage by creating barriers and obstacles for the further development of Italian manufacturing industries. Since the essence of Made in Italy is directly related to the intangibility of its name (image, design, creativity, and innovation), a strategically viable choice should be to protect the Made in Italy brand, by maintaining the headquarters, development of product design, production coordination, and quality control strictly in Italy [36].

Conclusions

As noted in the study of American reshoring, the participation of government at both the national and local levels is crucial for the adoption of reshoring. Italy needs to follow this example by legislating laws that attract the manufacturing industry back to Italy. The appropriate role of the government is to boost competitiveness among forces, as described in Porter's diamond and not to create simple advantages consisting of short-term costs through incentive policies [37]. Emphasis should be given to the Made in Italy brand, which is already recognized worldwide. As in the U.S., Italy has a knowledgeable workforce, manufacturing capacity, and energy capable of hosting energy-intensive industries. Actions that support reshoring are within the scope of policy creation and context: reduction of bureaucracy, legislation on labor, management and supervisory processes, tax incentives (such the implementation of a flat-tax rate), and the de-taxation of profits reinvested in R&D.

The partnership between industry, academia, and the public sector, as implemented in the U.S., is an example of an effort in the right direction. In recent years, in the U.S., a better-articulated policy strategy has emerged, European countries are still struggling to define an appropriate course of action to respond to the current global competitive challenges they face. The return of manufacturing to Italy is still considered a remote possibility for most Italian entrepreneurs, mainly because there are still many problems to solve in relation to the political and institutional framework of the country.

In order to increase a national baseline of knowledge and potential for growth, support for education and the creation of university centers of excellence becomes crucial. Attention should be given to innovative start-ups devoted to advancing manufacturing and improving global competitiveness. It is particularly relevant that all of the plans incorporate a progressive "fusion" of innovation and industrial policy. Networks promoting the transfer of technology from laboratories, universities, and research centers to businesses must be put into place, as it is currently being done in the U.S. The analysis of Italy and the Made in Italy brand highlights an industrial policy with limited resources, characterized by a dispersion of forces with different objectives and without an institution or organization that provides central coordination. Italy must count with the direct intervention of the government, providing economic and fiscal incentives that represent an opportunity to expand the manufacturing sector on Italian soil.

As in other countries, Italy must begin this process by strengthening the collaboration of public and private sectors and by establishing centers of excellence. It is necessary to structure an "innovation system" of the public and private sectors that promotes a network of research centers, universities and businesses, highlighting specialization, innovation, and participation of small- and medium-size enterprises in the process of generation and transfer of knowledge.

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Biographies

PATRICIA POLASTRI is an assistant professor at Texas A&M University and teaches courses in the Department of Industrial Management and Technology within the Dotterweich College of Engineering. While specializing in the areas of project and technology management, supply chain, and sustainability, before starting her career in academia, Dr. Polastri worked for many years in Europe and enjoyed the complexity of multinational organizations in the area of advanced manufacturing. Dr. Polastri is also a supporter of the Reshoring Initiative, seeking to promote the importance of global competitiveness in the manufacturing sector of our nation. In that role, Dr. Polastri was a guest speaker at the Krannert School of Management Conference at Purdue University. Dr. Polastri is a frequent speaker at diverse national conferences, emphasizing sustainable practices and social responsibility. Since 2012, Dr. Polastri has been the Faculty Advisor for the TAMUK student chapter of the Society of Manufacturing Engineering (SME). She was selected professor of the year in 2014 and 2015. In 2015, SME awarded her the Distinguished Faculty Advisor Award, and recently she was inducted into the Golden Key International Honor Society for her support and mentorship of TAMUK students. Dr. Polastri may be reached at patricia.polastri@tamuk.edu

ANTONELLA VIGGIANO is a visiting scholar at Texas A&M University, where she conducted her research. Viggiano received her bachelor's degree in economics and management in 2014 and her master's degree in management in 2016 at Luiss Guido Carli University in Rome. Mrs. Viggiano may be reached at antonellaviggiano@gmail.com

SIMULATION MODELING AND ANALYSIS OF A MANUAL BENDING LINE TO INCREASE PRODUCTION RATE AND RESOURCE UTILIZATION

Hamid Teimourian, Purdue University; Ali Alavizadeh, Purdue University Northwest

Abstract

In this paper, the authors report the process and results of discrete-event modeling and simulation of a manual suspension system assembly line. The company, where this project was completed, utilized about 12% of its capacity on that particular assembly line. The goal of the study was to examine whether a change in the number of operators would lead to an increase in productivity. Three simulation models were built and examined using two different scenarios. The results suggested that adding one additional operator to each of the workstations (Scenario 1) would increase the production rate, although the new operator would be under-utilized. On the other hand, adding an operator to alternate between two adjacent workstations and perform quality inspection and material handling (Scenario 2) led to a lower production rate, albeit with higher resource utilization.

Introduction

Simulation modeling has been used to solve problems and evaluate systems in different fields, such as manufacturing, business, management, and optimization. Simulation has been defined by Shannon [1] as, "the process of designing a computerized model of a system (or process) and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluation various strategies for the operation of the system."

Simulation modeling is one of the most-used techniques for studying and analyzing complex systems. By creating a simplified representation of a system, it is possible to improve system design, analyze cost-effective methods, change design parameters, and so on. Running the model results in the generation of system histories and, observing system behavior over time, its statistics [2]. A comparison between analytical and simulation models shows that one of the major advantages of discrete-event simulation is its ability to use standard and non-standard statistical distributions to predict the interactions between modeled random events [3]. In recent years, manufacturing companies have found discrete-event simulation techniques a quick, inexpensive, and non-disruptive alternative to traditional approaches. Managers and engineers have realized that, before making decisions on spending money to purchase more equipment, they can study the impact of such decisions using modeling and simulation [4]. This current project was conducted in order to investigate the effect of increasing the number of operators on production rate. Discreet-event simulation was used to model the sequence of the operation on this production line, and two possible scenarios were analyzed to select the most efficient one.

Background

The project was conducted in a Midwestern manufacturing company involved in the manufacture and assembly of truck suspension components, such as U-bolts for medium- and heavy-duty trucks. Figure 1 shows a suspension system U-bolt. The production manager and product engineer of the company stated that there was a significant gap (about 88%) between line capacity and actual production rate.

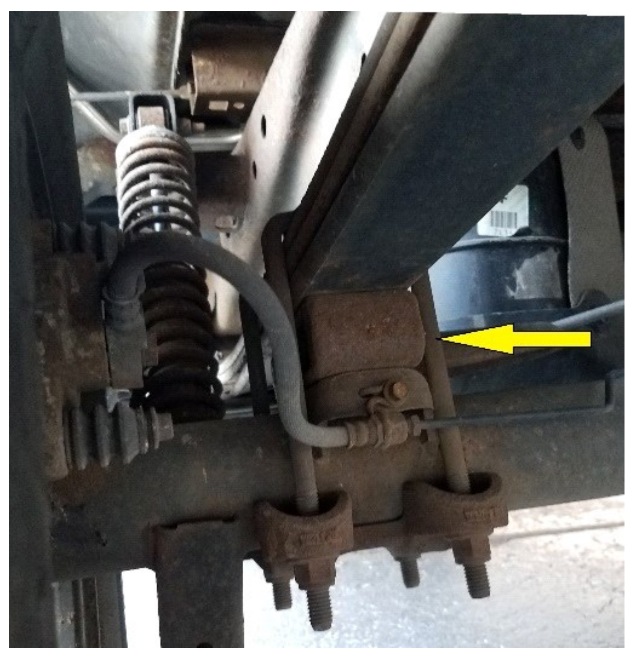

Figure 1. A Suspension System with a U-bolts (indicated by the arrow)

Operators of the machine performed inspections and moved finished products to the tubs that were used to carry them to the next station. Generally, cycle time for the process with inspections and material handling was 18 sec/pc, 200 pcs/hr. However, actual machine cycle time was 2 sec/pc, 1800 pcs/hr. The maximum lost output due to internal functions was 1600 pcs/hr. As only 12% of the capacity of the manual line was being used, the goal of the project was to increase productivity by maximizing resource utilization. There were four manual machines and one operator for each machine. In this study, computer simulation modeling was used to simulate the sequence of operations in both current and proposed future states of the system.

Statement of the Problem, Goals, and Objectives

The manual U-bolt production line of the company was under-utilized, thus the company sought ways by which it could achieve a higher production rate and improve resource utilization. The goal of this current study was to simulate a manual operation line to investigate the possibility of increasing production rate by adding more resources (operators) and changing their responsibilities. The outcomes of the project were to provide recommendations to the company to improve production rate and resource utilization, based on modeling the current operation and the results of running several simulation experiments. The model was used to study the effect of increasing the number of operators and their responsibility to maximize production rate and resource utilization.

Literature Review

The literature on the application of modeling and simulation in production line optimization is quiet rich. The result of surveys [5, 6], indicated various applications of modeling and simulation in different sectors, such as semiconductors and automotive. Ferreira et al. [7] used Arena software to model and simulate an automobile assembly line in order to study the impact of changing production sequences on line throughput. Hecker et al. [8] utilized Arena to optimize energy consumption in a bakery production line. Treadwell and Herrmann [9] studied various ways to implement pull production control in Arena. The authors basically added a new module to Arena to make it easier to simulate a Kanban system, and tested the module to evaluate its efficiency. Regarding Kanban systems, Al-Hawari et al. [10] developed a model to analyze the performance of an automated Kanban system. This production system had a supply of raw materials and generally distributed demand and service times. It was composed of three stations with different processing speeds. Stations were connected with a conveyer system to transfer parts between stations. Sensors were used on each conveyor to control the speed and stop state of the stations. Numerical methods were conducted to check model validity and study the effects of different parameters on system performance. Four numerical tests were conducted in order to study:

1. The effect of changing customer demand variability on system performance.
2. The effect of service time variability on system performance.
3. The effect of having different number of Kanbans in each stage on the system performance.
4. The effect of changing the sensor's position on the system performance.

Methodology

In this project, data were collected during the first shift for which the authors found that downtime for machine maintenance was negligible. The production manager recommended a focus on those parts that were being manufactured more frequently. As mentioned earlier, the production line for U-bolts at the company was under-utilized, which led to a low production rate. The production manager and engineer were looking for ways to increase production rate and to better utilize the resources. To address the problem, the current production line was studied first. The production line included four parallel workstations with a bending machine in each and one operator assigned to each. Each operator was responsible for the following tasks: operating the bending machine, quality control and paperwork, and material handling (including bringing raw material to the workstation and moving the finished product to the next station in batches using a tub).

Figure 2 shows the sequence of tasks. Basically, the workers bring individual metal bars (see again Figure 1) from the pool to the workstations then bend them on a bending machine individually (machine capacity was one). After making 100 identical U-bolts, they would inspect them and complete the necessary paperwork, put them in a tub in batches of 500 parts, then wheel them to the next station. The main focus of the study was to optimize these four workstations. The distances between the pool of parts and the workstations, and the distance between the workstation and the next workstation, were negligible. Figure 3 depicts an Arena model of the production system. It is worth nothing that, in order to model more complex operations, one has to use three process modules—Cease, Delay, and Release—as bending, quality, and material handling are being modeled (see Figure 3). This is the logic that Arena mandates. The batch module was used to represent the fact that parts were being processed in batches.

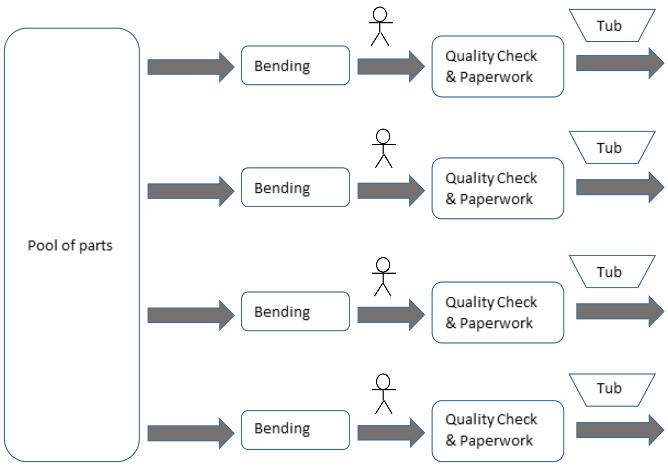

Figure 2. The Current Work Sequence of Making U-bolts

First Proposed Model

In this model, one additional operator was added to each workstation, who would do only quality control, paperwork, and material handling. Operator 1 would handle the bending, and operator 2 would be responsible for quality control and paperwork (2.1) and material handling (2.2) only. In total, then, four operators were added to the four operators currently on the production line (one for each bending machine). Figure 4 shows this first proposed model, which depicts one of the four operations shown in Figure 2.

Second Proposed Model

In this scenario, two additional operators were added, each assigned to two adjacent workstations. Each workstation still had an operator for the bending machine. The added operator, named swing operator, alternated between the two workstations to perform quality checks, paperwork, and material handling. These tasks were named Quality 1, Quality 2, Material handling 1, and Material handling 2. In total, two operators were added to the four existing operators (one at each bending machine). Figure 5 shows the model for two adjacent workstations.

Discussion

As mentioned earlier, there were around 500 different parts (each with a unique part number) that were produced at this company. Each of these parts had different technical specifications with different cycle time, thereby making data collection and modeling sensitive to time studies. After consulting with the engineering department, the cycle time of a sample of 300 parts was recorded during an 8-hour shift. Five replications were run in Arena for three different models: the Current Model (based on the current state of the production line), the First Scenario (adding an extra worker to each workstation to help with all tasks except bending), and the Second Scenario (adding two swing operators that alternated between two adjacent workstation to perform all

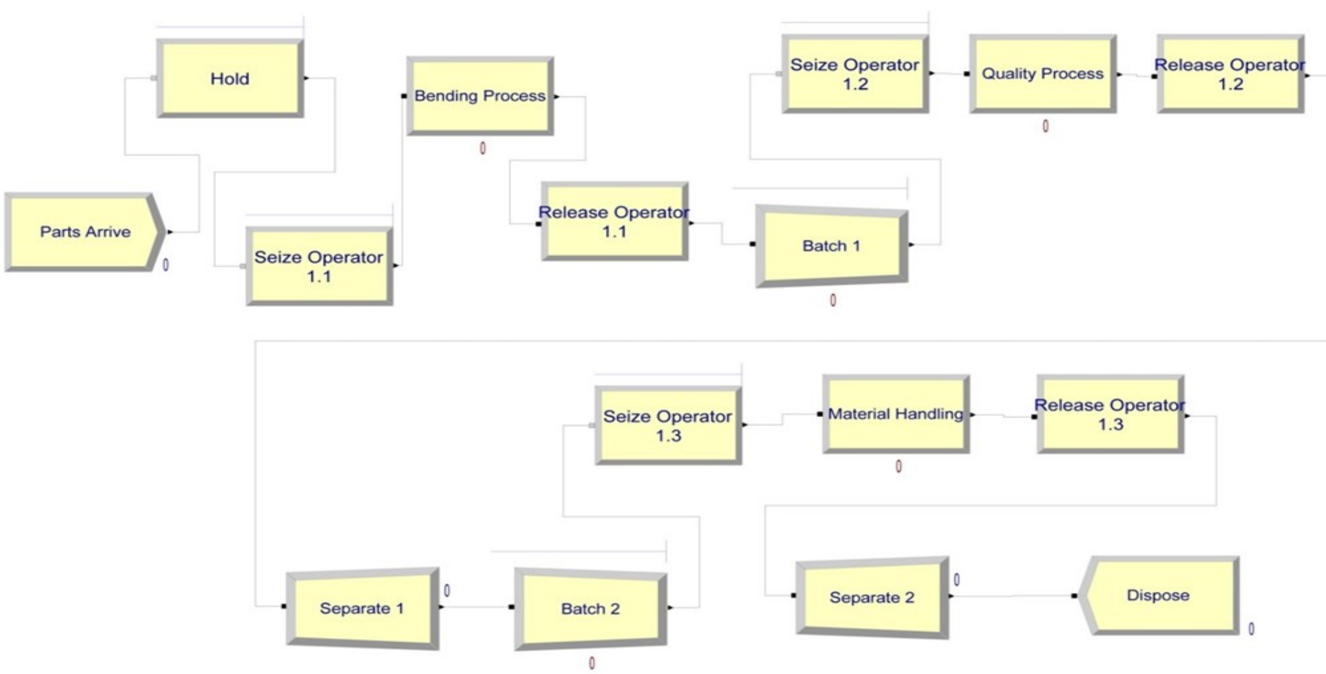

Figure 3. Computer Model of Each of the Four U-bolt Operations

Figure 4. First Proposed Model

tasks except bending). Table 1 shows the results of the simulation experiments (based on two adjacent workstations).

Table 1. Numbers of Parts Produced per Workstation at Each of the Four Workstation in Three Different Models

	Current	First Scenario	Second Scenario
Average Number	69,400	114500	87050
Replication 1	69,829	115873	88044
Replication 2	70,333	115874	88044
Replication 3	70,332	115874	88044
Replication 4	70,329	115873	88044
Replication 5	70,334	115875	88294

The simulated results of the current model were verified by the production manager to be fairly close. For the current model, operator utilization was 100%, although it was understood that, since such factors as work breaks and machine downtime were not being included in the model, the utilization would become 100%. Table 2 shows that resource utilization for bending was almost 100% for the current model, while for the first scenario, operator 1 was almost always busy, while operator 2 was not fully utilized. The reason for the under-utilized operator is that the bending cycle time was longer than the quality check as well as the fact that material handling would be done after 500 parts were finished. Therefore, operator 2 could not perform material handling until all of the 500 parts were produced.

Table 2. Resource Utilization in the First Scenario

	Utilization (%)	
	Bending Operator	Material Handling and Quality Control Operator
Replication 1	100	65.77
Replication 2	100	65.80
Replication 3	100	65.83
Replication 4	100	65.78
Replication 5	100	65.87

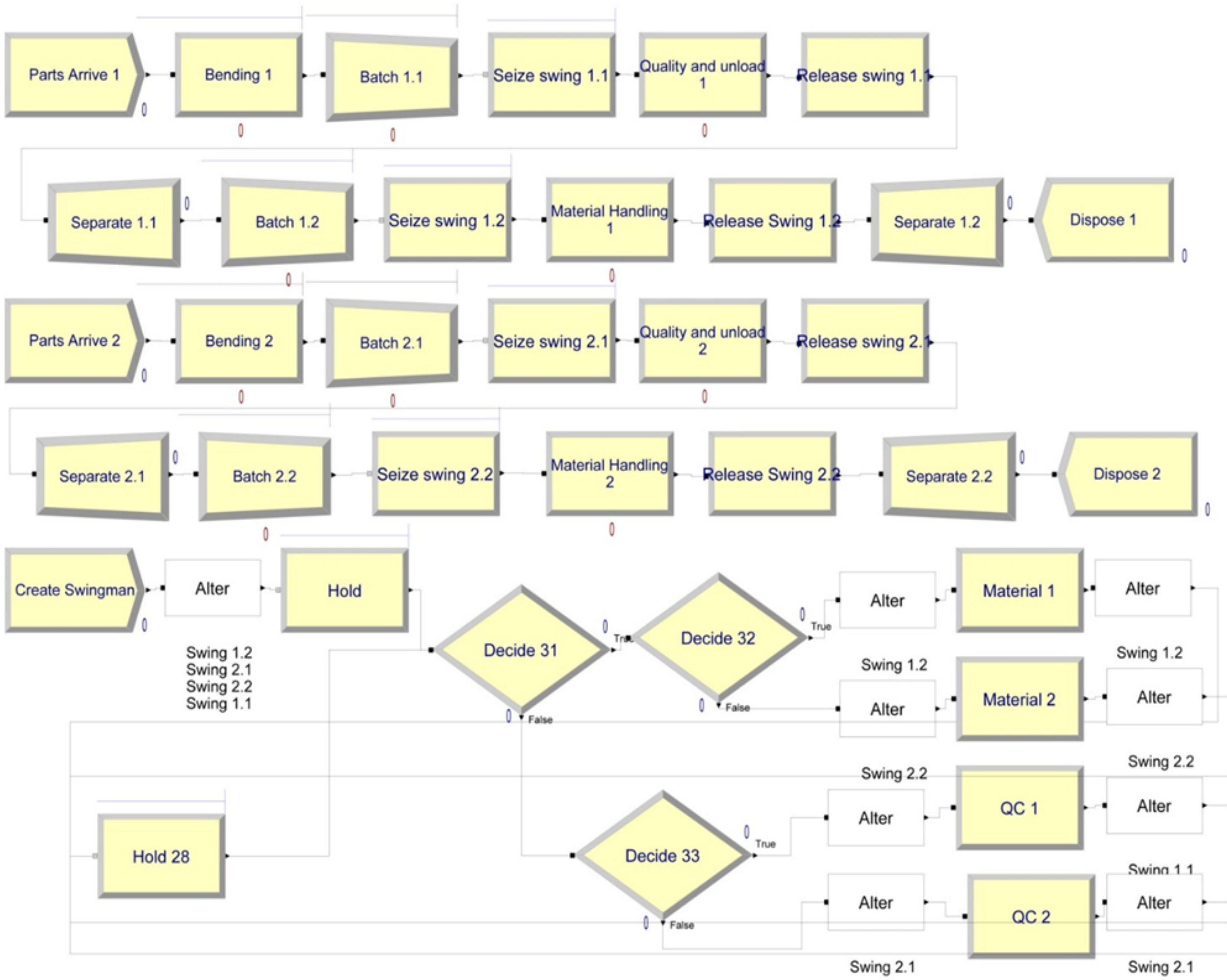

Figure 5. Second Proposed Model with Two Swing Operators

Table 3 shows the results for the second scenario, indicating that both operators of the bending machine were fully utilized. It is understood, however, that all of the results were based on simplified models, wherein, for example, machine downtime or operator breaks (for lunch, etc.) were not being considered. As far as the swing operators, as Table 4 shows, both would be fully utilized, though it was understood for these simulation results of a simplified model, that breaks were not being included. The swing man at each workstation was not able to complete the quality control and material handling of all of the parts produced by bending operators 1 and 2, whose number of processed parts are shown in Table 3. Therefore, at the end of the shift, there would be unfinished parts for the swing operators, which would result in a lower overall production rate for the second scenario shown in Table 1.

Table 3. Resource Utilization per Operator for Adjacent Workstations 1 and 2 (Bending Machine—Second Scenario)

	Utilization (%)		Parts produced at each bending station	
	Bending Operator 1	Bending Operator 2	Bending Operator 1	Bending Operator 2
Rep. 1	100	100	114532	114398
Rep. 2	100	100	114601	114504
Rep. 3	100	100	114523	114549
Rep. 4	100	100	114568	114481
Rep. 5	100	100	114547	114634

Table 4. Resource Utilization for the Swing Operator Working at Adjacent Workstations 1 and 2 (Second Scenario)

	Utilization per task (%)				Total Utilization (the sum of utilizations per task) (%)
	MH* 1	MH 2	QC*1	QC 2	
Rep. 1	19	19	31	31	100
Rep. 2	19	19	31	31	100
Rep. 3	19	19	31	31	100
Rep. 4	19	19	31	31	100
Rep. 5	19	19	31	31	100

* MH: Material Handling, QC: Quality Control

Conclusions

As mentioned earlier, the model is a simple representation of the particular workstations that do not take into account such factors as downtime and work breaks. Nonetheless, it provides useful estimates about the impact of resource modification (i.e., adding more workers) on production output and workstation utilization. It seems that, in all three cases (the current model, as well as the two scenarios), the bending machine operators are almost fully utilized, while the utilization of the additional operators in Scenario 1 is smaller. One recommendation is to change the bending operation's batch size to 50, or to decrease the material handling batch size. The impact of these changes are yet to be verified by either simulation or test runs on the floor.

When it comes to production rate, Scenario 1 seems to result in a higher rate. Therefore, management may adopt this scenario and hire four temporary operators to join the workstations, one for each, to help with quality control and material handling for special orders with high production volume (i.e., ramp-up production). Alternatively, management can partially adopt scenario 1 by adding two extra temporary operators to only two workstations out of the four. By partial adoption, one can observe the results of the implementation and, if possible, adopt scenario 1 entirely. Although it was not within the scope of this study, one detrimental factor in the implementation of either of the scenarios is an economic feasibility study, which is a future topic for the authors to explore.

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Biographies

HAMID TEIMOURIAN received his master's degree from Purdue University in 2014. His research work included working in different areas of industrial engineering, such as simulation modeling, reliability and maintenance, statistical analysis, operations research and optimization, continuous improvement, and manufacturing systems. His work experience includes working as a reliability and maintenance engineer in the oil field service industry and as a plant engineer in pharmaceuticals. He may be reached at hteimour2017@gmail.com

ALI ALAVIZADEH is an assistant professor of industrial engineering technology at Purdue University Northwest. He received his BS in physics from Sharif University of Technology, Iran, and PhD (Technology Management, 2007) from Indiana State University. Previously, he taught at Indiana University-Purdue University, Fort Wayne, the George Washington University, and Morehead State University in the areas of industrial engineering technology, and engineering management and systems engineering. His industrial experiences include software engineering, systems engineering and analysis, and production. His research interests include complex systems modeling and simulation and their applications in manufacturing and aerospace. Dr. Alavizadeh may be reached at aalaviza@purdue.edu

INTEGRATING ACTIVITIES, PROJECT, AND PROBLEM-BASED LEARNING INTO INTRODUCTORY UNDERGRADUATE ELECTRONICS COURSEWORK

Vigyan (Vigs) J. Chandra, Eastern Kentucky University; George Reese, University of Illinois

Abstract

Traditional freshmen-level electronics courses cover a broad range of topics, frequently interweaving theory and practical applications. As part of classroom and laboratory activities, it is important to provide students with opportunities for integrating their skills within a meaningful context. In this paper, the authors illustrate how concepts drawn from the Project Lead the Way (PLTW) curriculum can be integrated into introductory electronics courses for strengthening student learning. PLTW courses are based on an activities, project, and problem-based (APPB) learning model. This enables students to make effective connections between various sections of a course. The APPB learning strategies were adapted for developing a personalized mini-project in an introductory undergraduate electronics course. Following various in-class and laboratory activities regarding various electronics topics, students worked in groups for construction and customizing of a split-voltage power supply project. The project also included elements of specific real-world problems: adding custom safety interlocks and personalized displays in the design. This made constructing the supplies fun for the students and judging consistent for the instructor.

Anonymous surveys of the project experience indicated that the students had ample opportunities for making important decisions about their projects and that their confidence regarding working with electronic systems grew significantly. Integrating the APPB learning approach strengthened the students' understanding of the core content and essential skills by building a tangible electronic device. Students used the completed power supply in subsequent portions of the course. Some students also used the power supply in other electronics courses and for outside electronics hobbyist projects. Students continued to build on their understanding through the semester. The personal stake that students had in the project was a motivating factor in its success. The authors also discuss the challenges faced in adopting the APPB approach. These challenges include finding the time needed for completing student projects, while covering the topics required in a typical electronics course. Suggestions for addressing these challenges and organizing classroom materials around projects and problem solving are provided.

Introduction

Instruction in engineering- and technology-oriented fields is aimed at developing problem-solving, critical thinking, technical, and communication skills. In-class and laboratory activities, as well as course projects, should be used for developing students' abilities to design, implement, experiment, test, and troubleshoot systems. Alberts [1] points to the acute need for redefining science education, stating, "Rather than learning how to think scientifically, students are generally being told about science and asked to remember facts." The ASEE Engineering K12 Center [2] report suggests ways for improving education in schools and in outreach, including:

- an increased emphasis on hands-on (context based) learning activities
- adding an interdisciplinary flavor in all subjects by including technology components
- developing math and science curriculum based on state standards

Bybee [3], adapting the National Research Council framework elaborating on science and engineering practices, states that there is a need for "Asking questions and defining problems; Developing and using models; Planning and carrying out investigations; Analyzing and interpreting data; Using mathematics and computational thinking; Constructing explanations and designing solutions; Engaging in argument about evidence; and Obtaining, evaluating, and communicating information."

De Geeter et al. [4] regard development of problem-solving skills, critical thinking skills, interpersonal skills, personal responsibility, time management, and creativity through team participation in hands-on projects as being important for engineers of the future. By encouraging students to develop their own theories and solutions, this approach attempts to harness the inherent curiosity, imagination, and creativity of students, and thereby enable them to visualize alternatives and solutions. Making the learning process more meaningful to the students is a challenge, as they also need to learn about different criteria such as safety, benchmark testing, costing, and other standards that are needed, while determining the optimal solution for a technical problem. At the same time, instructors are faced with the dilemma of covering the content without sacrificing student interest.

Wiggins and McTighe [5] in their groundbreaking work, use a "backward design" process for actively engaging the students, so that they might discover ideas for themselves. This starts out by identifying the results or competencies instructors want the students to have, then determining the evidence that will indicate that the competency has been achieved. After setting the goals, the instructor plans the lectures and classroom activities that will steadily build necessary student competencies. For demonstrating true understanding of the subject, Meier [6] elaborates on the backward design strategy. She states that students should be able to explain, interpret, apply, have perspective, empathize, and exhibit self-knowledge. Addressing core questions of a subject will move students towards increasing competency and enduring understanding. In a related study, Bransford et al. [7] stated that significant transfer of learning has been observed by first having students work on sample scaled-down problems, supplemented by lecture, prior to working on more complex problems. Alper et al. [8] underscored the importance of having students see "mathematical structure in real-life" situations.

Project Lead the Way [9, 10] brings together several of these ideas in strengthening students critical thinking, technical, and communication skills. PLTW is a non-profit organization that has pioneered a unique science, technology, engineering, and mathematics (STEM) curriculum for middle and high schools in the United States. Over three thousand schools and half a million students participate in the PTLW program, providing a launching pad for future engineers and technologists. Johnson [11] points to successful partnerships that have been forged between public schools, institutions of higher education, and the private sector. PLTW uses the APPB approach for making STEM content more relevant from the students' perspective. Students perform activities, while building the essential knowledge and skills needed for solving class projects derived from real-world devices and systems.

Students synthesize knowledge for dealing with the complexity the problem presents. They develop their own solutions for problems that arise while working on their projects. This requires students to form new connections between the materials they have learned through prior activities and apply these in a relevant context. The positive impact of problem-based learning (PBL) on the conceptual understanding of electrical engineering students has been studied empirically by Yadav et al. [12]. Goncher and Johri [13] introduced constraints into the learning environment and studied the impact the context of the project had on the design process. The relationship between project design parameters—such as functionality, safety, innovativeness, and educational/entertainment—and the design process students chose and the actual design practices used was evaluated. They identified impediments to student achievement of specified learning objectives for design: projects being treated as isolated entities, linear design phases, cognitive inertia due to rigid timelines limiting redesign, and focus only on explicit constraints. They recommended use of content from other courses as part of a design project and, permitting sufficient time to allow for iteration of design phases, making transitions between phases smoother. Projects that include open-ended problem elements can provide ample opportunity for students to expand their understanding within the context of on a given project.

Instructional Strategy for Using APPB Learning

PLTW uses small, multi-day mini-projects. Rushton et al. [14] emphasized that course projects can often be overwhelming, since one has to design a solution to a problem with no fixed parameters, no fixed list of equipment to use, limited information—if any—about constraints, and no specified problem-solving methodology. Using a mini-project or linking multiple mini-projects can make this process more manageable. It also prepares students for larger projects further along in the curriculum, culminating in the capstone project experience.

Using mini-projects in the course provides opportunities for personalizing and inter-linking several lectures and laboratory activities [15]. These and similar activities allow students opportunities to personalize their projects by drawing on individual or group specialties and inter-link related information and skills while doing so. The course then is viewed largely as a cohesive whole rather than a mixture of disconnected topics. Using mini-projects shifts emphasis to student learning rather than to coverage of content. Extended time is spent on one theme or problem, and content coverage is interwoven in a natural way. Performance assessments related to the project require working designs, functional programs, and portfolio items. Collaboration is encouraged. Students design and showcase devices or systems that reflect their unique interests.

Development of the projects requires students to conduct online research, interact with peers, and learn new problem-solving strategies. When possible, they create simulations prior to actual construction of the device or system. From our experience, the mini-projects should be designed around interconnected essential topics of a course, or indeed across the curriculum, enabling students to see the broad utility of the device they are designing and implementing. For example, an electronic power supply constructed in an analog electronics course could be used for future laboratory activities within the same course, or in related courses such as digital electronics. Prior to implementing the projects, students need a background of associated knowledge and laboratory skills. They should know certain facts, theorems, notation, rules, and principles, as well as be able to do certain things like perform specific hands-on activities and procedures. In addition, the project should require group work, communication, initiative, and creativity on part of the students. The course project should be complex but personalized, and student groups should be able to complete it within the specified time.

Implementing APPB Learning in an Introductory Electronics Course

The APPB learning techniques integral to the PLTW instructional methodology were adapted for use in an electronic devices and circuits course. This freshman-level course is taken by different majors across campus and is not restricted to those pursuing electronics, computer systems, or networking undergraduate specializations. The prerequisite for this course is a fundamental electricity course. The initial portion of the electronic devices and circuits course is related to rectification and power control. The latter section of the course deals with transistors for switching and amplification. The transition between the two major sections was chosen as a location for implementing a power supply mini-project requiring design, customization, implementation, troubleshooting, and documentation. The pre-APPB version of the power supply project required its construction with a limited opportunity design customization based on student research into commercially available power supplies with regards to safety, ease-of-use, or personalization needs.

Students taking the electronic devices and circuits course were already familiar with the basic functioning of bench power supplies that they have used in the prerequisite course for performing various laboratory experiments. In order to build interest about the topic, students considered sample power supplies in systems they use on a daily basis, such as those in computer systems. The significance of power ratings can be readily conveyed by examining the power requirements of high-end video cards needed for online gaming, a topic that is likely to be of interest to students. Sample power supplies from different computer systems, along with laboratory power supplies, were used to motivate the construction and subsequent customization of a split variable-voltage regulated power supply.

Safety considerations regarding the power supply are paramount. Rather than provide specific guidelines for the safety interlocks required for each power supply, students were asked to brainstorm ideas in groups. Groups examined what they considered would be the safety features of commercially available power supplies, along with the safety features used in automated systems. This interaction helped to internalize safety concepts and made them more aware of why certain functions are added in devices. The instructor was watchful to ensure that no important safety concepts were overlooked. In a study for establishing links between learning activities and outcomes in problem-based learning, verbal interactions by students were studied by Yew and Schmidt [16]. They identified a concept articulation phase and a concept repetition phase. By increasing verbalization of concepts during the different phases of the problem-solving process, students were found to improve learning outcomes.

In the context of the electronics power supply project construction and extension activities for including safety interlocks, encouraging verbalization of the knowledge, skills, and professional practices being used can be helpful for students working in teams. This type of collaborative interaction can allow students with widely varying skills to teach and learn electronics concepts in a group setting. After the power supply was built and tested, it was used by different groups in subsequent portions of the course and also for other courses in the electronics area. The dual-voltage power supply is particularly helpful for various transistor amplifiers. The power supply provided students insight into solving realistic problems that span multiple content areas. The practical applications of course content helped to deepen the students' understanding. Troubleshooting and problem solving were integral to successfully completing the project, with students trying to apply what they had learned through structured classroom discussions and activities for solving the problems that arose. Addressing real-world problems, such as safety hazards within the context of their power supply, and becoming informed by their online research and class discussions, can increase student involvement and ownership of their learning process.

Results

All student groups successfully implemented the dual-voltage power supply project, including construction, customization, troubleshooting, and documentation. Considerations for project evaluation were based on power supply design and safety interlocks, group number display, outside and inside appearance (casing), soldering quality, demonstration of the variable voltage of the dual regulated power supply within specifications, and the project report.

Figure 1 shows representative power supplies built by students as part of the mini-project.

Figure 1. Sample Power Supply Projects with Safety Interlocks Designed by Students

The safety interlocks that students added to their project following group discussions included activation of buzzer alarms and flashing LEDs when the case was opened, along with deactivation of the unit, key locks, cooling fans along with appropriate ventilation, digital voltage level indicators, external quick-acting switches, a spring "hammock" for the power supply PCB for protecting it against excessive vibrations, transparent enclosures for immediate visual information about components, and multiple types of interconnected switches monitoring conditions inside the power supply. The report for the mini-project was similar to an expanded laboratory report, with prompts requiring students to provide their ideas from brainstorming sessions, along with the completed designs. It also included the implementation steps, observations, troubleshooting procedures, results, conclusions, directions for use of their power supply, activity logs, list of references uses, and digital photos of the project. A project report template was available online for the students. While a majority of the project reports met all of the requirements, it was observed that students had difficulty in developing appropriate diagrams for the customization portion of the project. This was in part due to the different types of sensors used as well as the mechanical safety interlocks added by some groups. Also, many students seemed to rely on their recollection of the activities performed, while filling out the activity log portion rather than filling it out right away.

After completing the power supply project, students completed an anonymous 10-item survey. Five-level Likert items were used for determining student reactions regarding different aspects of the power supply project. The responses of the 16 students who took the survey are summarized in Figure 2(a-j). Almost all (93.75%) of the students indicated that the instructions for the mini-project were clear and that they understood the steps involved in constructing the power supply as well as the importance of safety. Almost all members of the different groups interacted closely while participating in the project. While the class was split evenly about their perception of the prior understanding they had about power supplies, most of the students (93.75%) agreed that their personal experience while working on the power supply increased their confidence about working with power supplies, with 75% agreeing strongly to this survey item. Students gained a better appreciation for the compact and efficient design of commercially available power supplies with multiple regulated outputs. Students used practical and innovative ideas for integrating safety into their power supply units.

Some of the student comments regarding the power supply project:

> "The power supply project was an excellent <u>learning</u> opportunity. Not only did it teach about the electronic operation of power supplies, it also taught about the various processes involved in electronic circuit construction. There was also the challenge of design and layout."

> "I loved working on the power supply project! I found myself always wanting to add things to it, and I always looked forward to tweaking things on it."

> "The power supply significantly improved my understanding of electronics and of how power supplies functioned and made me feel much more confident in my knowledge of electronics. I think it would be terrible idea to drop the power supply project in future semesters of this course!"

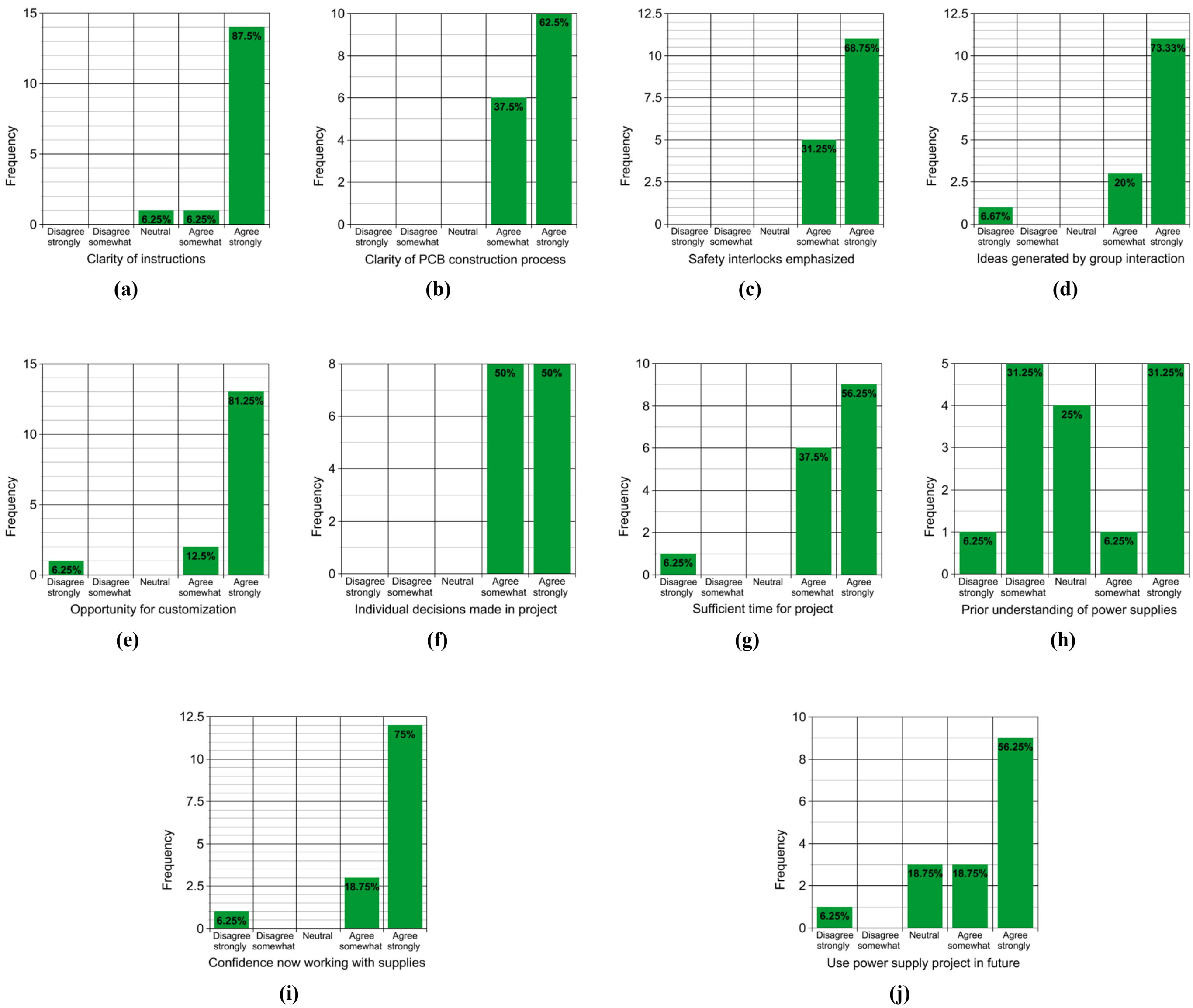

Figure 2. Power Supply Survey Results

Some of the challenges associated with the project:

"[Group] partner didn't want to help outside of class."

"Personally I did not have much time out of class to spend on the power supply."

Some of the suggestions provided by students for future improvement of the project:

"I think it might be better to have to do the project later in the class. Everyone seems to drop everything else as we worked on the project."

"I would like to see more check points and deadlines to show a gradual build of the supply over time and possibly 1 week more to complete the supply."

Challenges and Implications for Learning

The different phases of the power supply mini-project presented several logistical issues. With a full class working on the project, equipment such as drills and miscellaneous tools were is short supply, especially during the PCB etching process and power supply assembly. While the project was intended to be completed within five class periods, reworking and troubleshooting of circuit boards took more time than planned. Several of the groups had to work outside of class time to get the project completed. There were also delays associated with ideas needed for the safety interlocks and customization needed through group brainstorming sessions.

The biggest challenge was providing sufficient time for the project, while moving ahead to subsequent topics in the course. Additional class time was allocated during the semester for completion of the project. Content coverage of other areas of the course was reduced, owing to extended time spent on the project. Assignment of online Web readings or videos is planned for supplementing classroom instruction, particularly on advanced topics. Also, assessments in class should include an open-book section. By assigning project-related homework, students will be able to complete part of the work outside of class time. Instructors can also choose to use comprehensive exams that include content from the project so that students will use these as opportunities for reviewing the essentials of the entire course. Instructors can help students with organizers that identify underlying themes. Block diagrams and concept maps can graphically illustrate key ideas and linkages. These can be referred to time and again, especially while transitioning to different sections, so that students view the course as a coherent whole.

Balancing the contribution of individual group members is another important challenge. Rubrics that show students what is expected in professional interactions can be used for this purpose. These could include criteria for collaboration, sharing of responsibilities, or the roles of different group members. Reducing group sizes to two or three students and requiring self-reflection statements on the contributions to the group objective may be used. It is essential that adequate resources are available for all groups/students, and this may require separating essential equipment for the project from that shared with other classes. It was observed that the activity log for the power supply project was not updated regularly, as students were absorbed in the actual project activities. In future offerings of the course, there are plans for including project management software that will enable students to track progress and allocate time and other resources optimally. Time permitting, the use of multiple, interlinked projects in the same course will provide students with practice developing additional topics. It may be possible to modify or upgrade the mini-project developed in an earlier portion of the course for use in subsequent sections. Similarly, using projects created in prior classes will show students linkages across the curriculum. Requiring submission of the final project report later in the semester, and with an interim version, is being considered.

Overall, even considering all its challenges, the use of APPB-based learning in the electronic devices and circuits course turned out to be a rewarding experience. Students enjoyed working on a realistic and relevant project that they could use for other electronics laboratory activities, and even outside of class. Accessorizing the power supply required creative and critical thinking on the part of the students, while they developed technical solutions that could be applied in a personalized context.

Conclusions

Using carefully selected projects that lend themselves to personalization by students increases their grasp of technical material and enables faculty members to convey key concepts effectively. The theoretical underpinnings of problem-based learning as identified by Marra et al. [17] include constructing knowledge stimulated by a question, need, or desire by interacting with the environment and embedding learning within a context similar to one in which it will be applied. They note that working on an authentic problem improves metacognitive skills and helps students construct knowledge, make meaning, and learn. Any foundational project used in the technology curriculum, such as constructing an electronic power supply in an electronics course, can, with relatively minor changes, include open-ended problems in its design.

Improving safety, functionality, efficiency, aesthetics, and accessorizing it based on online research of commercially available equivalents allows students the opportunity to actively engage in the learning process. The opportunity for using and re-using a tangible product that the students created and customized in a freshmen-level course all the way through their senior-level capstone makes it possible to embed learning that lasts into the fabric of the course. Student survey data from the course indicate that students are eager to build practical applications blending relevant theory with practice. By structuring the classroom activity so that thinking and action go hand-in-hand, students get prompt reinforcement about whether their designs or suggested solutions will indeed work. The next steps will be to create comparison groups for measuring differences in performance outcomes in APPB and non-APPB.

The APPB learning that is an integral part of the PTLW curriculum can be used as illustrated in this paper to integrate topics in meaningful ways at the introductory undergraduate level. Successful completion of individual stages of the project gives students confidence for seeing a task through and encourages them to take on complex projects in subsequent classes. This, in turn, may spark and sustain interest in the electronics field and aid student retention in technology and engineering fields. The relative ease with which almost any technology project in the curriculum can include elements of the APPB model—specifically open-ended problems requiring customization based on online research, discussion, and experimentation—has the potential to personalize learning and, thus, make it more enduring.

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Biographies

VIGS J. CHANDRA serves as coordinator of the Network Security and Electronics Technology-related programs offered within the department of Applied Engineering and Technology at Eastern Kentucky University. He earned his doctoral degree from the University of Kentucky in electrical engineering. He is the recipient of the 2013 Golden Apple Award for Teaching Excellence at EKU. He may be reached at vigs.chandra@eku.edu

GEORGE REESE is director of the Office for Mathematics, Science, and Technology Education in the College of Education at the University of Illinois. His research interests center on the application of new digital technologies to K-12 instruction. He is currently a board member and president-elect of the Illinois Council of Teachers of Mathematics. Dr. Reese may be reached at reese@illinois.edu

LESSONS LEARNED IN CROSS-COLLEGE COLLABORATIONS: AN ENGINEERING AND EARLY CHILDHOOD EDUCATION DESIGN PROJECT

W. Neil Littell, Ohio University; Sara Hartman, Ohio University

Abstract

While the benefits of cross-college collaboration are known, these collaborations are often challenging for faculty members to facilitate. However, collaborations such as the one reported in this study offer rich opportunities for cross-content learning and professional growth. An examination of this collaborative process is of value to researchers who engage in cross-disciplinary collaborative work. In this pilot study, the researchers examined the collaborative process that occurs when students majoring in engineering collaborated with students majoring in education to design and construct exhibits to be used in an informal learning setting for children. The students collaborated to design exhibits that were functional, durable, and developmentally appropriate for children. Specifically, engineering students in the Russ College of Engineering designed an interactive, hands-on exhibit for a local discovery museum. Early childhood students in the Patton College of Education collaborated with the engineering students to provide design insight about developmentally appropriate features, safety considerations, and providing multiple levels of engagement. Researchers observed the collaborative meetings between the students and conducted follow-up interviews with students from both colleges. Qualitative data collected from interview questions, field notes, and written participant reflections were coded to create a system of categorical aggregation, which allowed for patterns and multiple instances of data to be readily identifiable. Where appropriate, direct interpretation was used for single instances or vignettes that emerged from the coded data.

Background and Justification

Despite the benefits of interdisciplinary project-based learning experiences to positively impact student learning outcomes, college programs often act in isolation from other majors of study [1]. Engaging in cross-college collaborative work often poses challenges that present impediments to meaningful and ongoing facilitation of collaborative projects [2, 3]. When collaborators persist in the face of challenges, rich opportunities for cross-content learning and professional growth may emerge [4-8]. In this pilot study of cross-college project-based learning, the researchers examined the collaborative process that occurred when engineering and early childhood education students partnered to design and construct exhibits for use in an informal learning setting for children. Students collaborated to design exhibits that were functional, durable, and developmentally appropriate for children. Specifically, engineering students were asked to design an interactive, hands-on exhibit for a local discovery museum, while early childhood education students provided design insight about developmentally appropriate features, safety considerations, and providing multiple levels of engagement. The researchers investigated the following research questions:

1. In what ways were the finished design products impacted by the collaborative process?
2. Is the collaborative model one that is feasible and productive for future projects?
3. What best practices may be identified for duplicating the collaborative process?

The findings from this pilot study inform best practices in the development and implementation of future cross-college collaborative partnerships. An examination of this pilot study is of value to practitioners wishing to design collaborative experiences for their students, and for researchers engaging in cross-disciplinary, collaborative work with an emphasis on project-based learning.

Literature Review

Project-based learning (PBL), which may trace its roots to the student-centered educational work of Dewey's [11] "learning by doing" movement, is inherently collaborative. In today's college classrooms, PBL represents a progressive trend that focuses on the process of learning, as opposed to the method of teaching [4]. Project-based learning is the "effortful process" by which "powerful interactions between cognitive engagement and motivational drive" [12] create an environment in which active learning flourishes and students and the intellectual problems they face are the primary focus of classroom learning experiences. Ideally, PBL should be an arena in which students are presented with interdisciplinary problems where "the answer" is not clear and something practical and tangible is produced as a result.

While no instructional method is perfect, PBL attempts to create an environment that is the opposite of what higher education is often criticized to be: too much top-down dissemination of content and too few practical, hands-on experiences. Though direct instruction is one of the primary methods of instruction in higher education classrooms, it is considered a poor option for delivering content and concepts in an interactive and engaging manner [4, 6, 8]. Active learning, when students are engaged in creating knowledge, is almost always more conducive to learning than direct instruction [12]. Both within specialized engineering courses and across disciplines, PBL methods are associated with increased student learning outcomes [4-8]. Studies report that PBL increases student interest and motivation in course content [7-9], positively influences student self-efficacy [5, 13, 14], and encourages active engagement in the learning process [6, 10]. Further highlighting the value of PBL as an instructional strategy, research by Chua [4] suggests that college students who regularly engage in PBL experience fewer conflicts during collaborative projects, an essential life-skill that has implications for future career success.

Although cross-college collaborations may be challenging to facilitate, when collaborations do occur, they are often project-based [1]. Despite the known benefits of collaborative PBL, successful implementation is not without challenges [1]. Developing partnerships across colleges and programs requires persistence. Indeed, it can be challenging to find and maintain community contacts within both community and university settings [8, 15]. Institutional structures such as scheduling, resource allocation, and course learning outcomes sometimes contribute additional constraints [16]. To allow for cross-college collaborations, instructors must work creatively to find compatible meeting times and spaces and to identify and develop appropriate course outcome alignment [17]. Research suggests that seeking to overcome barriers is a worthwhile endeavor, as collaborative PBL experiences resonate particularly well with millennial students, who seek social interactions in conjunction with content knowledge acquisition [15]. PBL can create a sense of community, not only among fellow students in the same classroom but also among those in other majors [10]. Referred to as disciplinary egocentrism, interdisciplinary PBL also encourages students to examine topics from outside their own discipline, giving them the opportunity to develop an understanding of how other disciplinary content may influence their understanding of the PBL tasks and goals [10].

Maintaining collegial relationships over the course of several semesters and still providing meaningful work for students introduces a further challenge; however, using project-based instruction may help to motivate students to perform in ways that traditional assignments do not [8]. As with any teaching pedagogy, implementation is key. Some studies find that, in university settings, PBL is frequently used as a form of final or capstone assessment [5, 18, 10] rather than the primary vehicle by which students learn and create knowledge. While the work that the students are showing in these projects can be substantial, ideally PBL should be an ongoing formative assessment utilized to create meaning and knowledge rather than an end-of-the-road summative assessment to demonstrate what has already been learned. Instructors need to be aware of the challenges mentioned above in regards to faculty oversight and realize that projects must be realistic in terms of resource management and student development expectations [17]. If faculty can achieve this balance and generate enough buy-in for the students, authentic student learning is achievable, and the struggles to create an enriching PBL experience become worth the effort.

Project Overview

This pilot project existed as a collaboration between a junior-level engineering design class (ETM 3010 – Engineering Graphics Applications) and a junior-level education class (EDEC 3500 – Early Childhood Social Studies) at Ohio University. The objective of the project was to allow both groups of students to work together to create and validate a product design portfolio. The project requirements were provided as an open-ended design project, requesting design proposals from the engineering students for a discovery museum. The theme of the project was green energy. The final project deliverable was a preliminary design proposal and design review that the engineering students presented to their instructor. This project was conducted across a six- week timeframe and encompassed three course outcomes for the engineering students and two course outcomes for the early childhood students.

Engineering Design Course Overview and Selected Course Objectives

ETM 3010, Engineering Graphics Applications, is a junior-level design class. Prerequisites for this class include a freshman-level introduction to engineering graphics class in which the students are exposed to fundamentals. Several manufacturing process classes are also prerequisites to ensure that the students have an appropriate manufacturability background. These prerequisites are intended to ensure that the students understand enough about manufacturing processes that they can document the design of parts using modern engineering design standards and ensure that they can design parts that are actually manufacturable. The design project in this study specifically assessed three of the course objectives of the class:

Course Objective 1: To provide students with an understanding of the product realization process.

By providing a loosely defined design project, the students are required to investigate the design project to develop their own requirements. The investigation process alone is one method of design synthesis where they begin to conceptualize the finished product. From the initial concept, the students are required conduct the analysis (how the product will function) and the design (what the product will look like) of the finished product. This process typically yields several design iterations where the group will discuss the design project and the feasibility of different design solutions to the central design problem.

The execution of a selected design will begin with concept sketches and a written description of the museum display. The students will then begin to design the components that are required to build the project. Through this process, they will consider manufacturability as well as which components should be purchased off the shelf or custom fabricated. The integration of these parts into the final project is the culminating task of this objective.

Course Objective 2: To expose students to the types of documentation and analysis commonly used during the product realization process.

The engineering students had to perform multiple types of documentation and analysis to discover the optimal mix of design solutions. For example, the students completed a house of quality as a method of discovering customer requirements as well as functional performance metrics for the product. Additionally, they completed a failure mode and effects analysis against their product to identify and control hazards with their design. A product structure and costed bill of materials were required for identification of cost targets. The three-dimensional designs drove the production of the engineering data as well as the engineering prints.

Course Objective 3: To allow students the opportunity to use engineering prints as a communication tool from both the creation and interpretation perspective.

The deliverables from Objective 2 provided the foundation for a product portfolio and the final design review presentation. Through the development of these deliverables, the students articulated their understanding of the customer requirements and their design solution to meet those requirements. The design review presentation provided a platform for the students to present their work to their peers, as well as providing an opportunity to answer questions and to determine if their design solution satisfied the requirements of the product. Design reviews also served as an opportunity for the design group to discuss manufacturability challenges and to articulate concerns with their design against the product requirements.

Early Childhood Development Course Overview and Selected Course Objectives

EDEC 3500, Teaching Early Childhood Social Studies, is a junior-level course for students majoring in early childhood education. The course focuses on developing curriculum and instructional practices that support social studies learning across disciplines and contexts. Emphasis is placed on identifying and practicing approaches and instructional strategies that will engage children in concepts such as families, community, and living in a diverse society. Integral to the course is promoting the development of engaged and involved citizens within a democratic society. As part of their clinical placement work, students taking the course also spend an average of 250 contact hours with young children during the semester.

Course Objective 1: To acquaint students with the major themes of social studies education.

Social studies is the integrated study of the social sciences with a focus on promoting civic competence. As a school subject, social studies brings together the study of geography, history, civics, anthropology, sociology, and economics [19]. The early childhood social studies methods course is designed to promote understanding of social studies content in order to further student awareness of the integrated nature of social studies curricula and instruction. The design collaborative described in this project required students to apply knowledge of early childhood development and pedagogy in a hands-on, authentic manner that will be replicated in professional education settings. Additionally, the project promoted understanding of each component of social studies core content areas.

Course Objective 2: To emphasize the need to encourage civic engagement and democratic discourse through social studies content.

Training teacher leaders who recognize their potential to be community change-agents is a foundational component of the early childhood social studies curriculum. Course outcomes place specific significance on encouraging early childhood teacher candidates to embrace civic engagement and to be leaders in their field. Engaging in a collaborative partnership across disciplines and with a community entity is itself a valuable act of civic engagement. Also, the collaborative discussions that occur during design meetings provide authentic opportunities to engage in democratic discourse. Community involvement is a key concept in social studies methods courses, connecting this project-based collaborative experience directly to social studies methods course content.

Methodology

Both classes were divided into seven groups, and each of the groups selected a different green energy technology to investigate and for which to develop a proposal for a museum display. To control the scope and complexity of the designs, the volume of the displays was limited to a 4'x4'x2' volume. The intention was for the engineering students to work towards the development of mobile displays that could be easily deployed in multiple venues. The engineering students were expected to extrapolate their design and performance requirements from the open-ended project scope. The Early Childhood Development class was divided into similarly sized groups that were then paired with the engineering students. The engineering students provided the education students with a brief write-up of their projects a few days before a planned meeting. Both classes of students joined each other in a neutral location (a large classroom), where they participated in a 10-minute team-building session (Figure 1). After this session, the students participated in an open review and discussion of their designs, potential issues, and concerns.

Figure 1. Engineering and Education Students Collaborating to Design Museum Displays

After this meeting, the engineering students worked to incorporate design changes. The researchers requested the voluntary participation from the student study participants and interviewed them. The group interviews consisted of 2-4 students who were assigned to a design project. Table 1 illustrates the use of categorical aggregation [20], where the results were coded to allow for patterns and multiple instances to be readily identifiable. The coding system was inductive and guided by the research questions. As such, interview data were coded according to: a) impact of the collaborative process on design features, b) productivity/feasibility of the process, and c) best practices for future collaborative work. To ensure validity and reliability of the data, researchers utilized methodological triangulation via multiple data sources [21]. For example, data sources included field notes from collaborative meetings, student exit notes, and interview transcriptions. Obtaining multiple perspectives on the same event was essential to validate the research.

Table 1. Codes and Definitions

Category	Codes	Definitions
Design Features	Design features modifications	Students explaining how the collaboration resulted in modifications in the design features.
		Students explaining how the design features were not modified as a result of the collaboration.
Feasibility/ Productivity		
	Participatory experiences	Students expressing enjoyment or dissatisfaction with the experience.
	Perceptions of the value of the experience	Students describing what they gained educationally and/or as professionals from the experience.
Best Practices	Insights of what made the experience positive	Students recommending specific practices that should continue for future application.
	Insights about what might improve the experience	Students describing specific practices that would improve future experiences.

Results

In what ways did the collaborative process impact the finished design products? The engineering students received the design requirements and then worked towards the completion of their design. However, their design did not meet some of the fundamental requirements of the product in application related to the early childhood stakeholders of their product. This was evident by the interactions between the two groups.

One explicit example of this involved a project designed to illustrate hydroelectric power principles. The concept of the display centered around creating electricity by turning a water wheel. The exhibit existed as a game where two participants could compete by using a carnival-style water gun to squirt water at a wheel. Two participants would play by facing each other during the contest with the display between them. The participants scored points by making the wheel turn from water that squirted from the top of the wheel with their water gun. The defending participant could counter by using the water gun to block the wheel from turning by directing a stream of water to counter the opposition. An electronic device would determine the number of revolutions in a particular direction to score points for a player. Points would be displayed via a series of lights for each player, and a race car would move forward or backwards on a track to indicate if they were gaining or losing power.

Once one player achieved a certain number of turns (perhaps 100 more than the opponent), the game would indicate the winner and reset for the next player. It is important to note that the entire display was designed as an enclosure to keep water from escaping during the event. When asked what features of the display were their favorite and why, the engineering students stated: “I would say the fact that it was competitive.” Their education counterparts echoed this by stating, “I like that they had them as race cars. Not just one person doing it, but there was another person from the other side.” While reviewing the project, the education students mentioned that it was inappropriate for children to use guns in an educational setting, and some may not have the fine motor coordination to pull the trigger and control the gun. Though the engineering students in the group disagreed with this perspective, they were eventually persuaded to change the water squirting mechanism to a steering wheel with a button to squirt the water. One engineering student reported that “They wanted to remove the title of squirt ‘gun’ and I felt that we were defending ourselves during our time.”

This was the most pointed example of design changes experienced during this project. However, all of the collaborative design groups reported changes to the projects to make them more appropriate for the end users. Many of the changes concerned signage, color usage, safety considerations, and making the displays more developmentally appropriate. In general, the engineering students agreed with and accommodated the requests by the early childhood development subject-matter experts. The engineering students unanimously agreed that their products were better when the products incorporated the advice of the education students.

Is the Collaborative Model One That Is Feasible and Productive for Future Projects? This project was well received by both groups of students and, in general, appeared to be a rewarding and validating experience for each of the groups. For the engineering students, this project provided an unstructured exercise that required them to be creative to synthesize an ambiguous project scope into discrete and well-defined products. For the education students, this project provided a real-world, authentic experience, where they could work as subject-matter experts on an applied project. The students in both groups unanimously agreed that this was a valuable experience. The students also unanimously agreed that they had never had this experience outside of their own college. They did offer some suggestions for improving the experience, which will be discussed in the Implications section of this paper.

What Best Practices May be Identified for Duplicating the Collaborative Process?

While the results of the project met (and in many cases exceeded) the learning objectives, the scale of this project was aggressive for a six-week class project. The project was even more difficult because it occurred at the beginning of the design class. Even though this is the second design class in the engineering curriculum, the students need more time to explore the design process, beyond simply creating engineering drawings (the focus of the first class). The next time this study is run, it will be for a longer duration and will start later in the class to allow the students ample time to work on the project. This will give both instructors and students more opportunity to explore the engineering design process, which should help with requirement gathering, product sketching, and knowing the other students’ strengths to allow them to format a prospective design for a preliminary design review.

Due to work styles of participating students, making group placements more purposeful will also be a component of a fully implemented study. Additionally, as this project was a large project, it was executed as a single deliverable. Engineering students noted informally that they could have created better designs if there were several design checkpoints where they could receive feedback from their peers, their early childhood collaborators, and the instructors of both courses instead of one large project grade from their instructor. Prior research reveals that PBL is best in an environment that offers ongoing formative assessment [10, 18]. Planning for multiple meetings over the semester would also allow the PBL component to be an ongoing formative assessment in both courses.

Challenges

Students commented about a clear disconnect between the classes. Specifically, what does each major do and what are they going to contribute to this project? Some education students commented at the beginning of the project that they were not clear what they could contribute. These communication perspectives and misconceptions were echoed by the groups, stating that they were anxious and/or nervous to meet with their counterparts to pursue the project. At the beginning of the project, the engineering students were concerned that the education students would want to change their designs once they were almost complete, and the education students were afraid to speak up because they knew that the engineering students had already put forward almost a month of work. Scheduling was also a challenge, because the classes met at different times.

Implications

While this pilot project seemed to be a very rewarding experience for everyone involved, it should be noted that educators wishing to replicate a multidisciplinary educational experience such as this should expect some growing pains. They should expect to resolve perception misunderstandings between the two majors, and they should work to proactively educate the collaborating students in the other's strengths and content expertise. The first meeting should focus on resolving misunderstandings between what the students perceive their counterparts do and what they will have to offer the project, as well as a team-building experience. Depending on the nature of the collaboration, educators may need a survey to discover prior knowledge and assumptions about their counterparts (content knowledge) and the types of jobs they will likely pursue once they graduate. Educators should allow their students to identify and verbalize what they themselves can do. These surveys should be openly reviewed with both groups to assist in understanding the roles and responsibilities of the individuals within the group.

Recommendations and Future Work

Through this pilot project, the authors learned that it is important to connect the students from the beginning to give them as much time as possible to work together. Facilitators should work to discover and address any preconceived notions between the classes, and each class must have an equal stake in the project. Student groups should be paired together along with a team-building exercise, and they should be prepared to receive constructive criticism concerning their projects.

When this project is offered in the future, it will exist as a culminating experience for the class. The teams will work with each other more frequently and closely. The grade of the project will be tied to the students equitably so that each engineering/education team must truly work together to achieve the design objectives. It was observed that many of the students became very involved with their design projects and wanted to see them develop into actual products. While this was not possible due to time and monetary constraints, it is recommended that at least one of the designs be prototyped into a physical display that could be installed locally at an informal learning site.

There may also exist other possibilities to partner with students from other departments, such as art or marketing students. The art students could greatly assist both groups of students with the aesthetics of the signage and the products. Marketing students could help develop an advertisement campaign to increase awareness of the displays and to help drive traffic to the exhibits. While these types of interactions could be valuable for creating an authentic learning experience, more cross-college and even cross-university collaborations should be pursued to determine a comprehensive procedure for developing the experience to achieve the optimal experience and assessment of the learning objectives.

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Biographies

W. NEIL LITTELL has a PhD in Instructional Systems and Workforce Development from Mississippi State University and is an assistant professor in the Department of Engineering Technology and Management in the Russ College of Engineering at Ohio University. Before coming to Ohio University, he acquired over a decade of applied industrial experience helping companies design and launch new products. His research interests include product lifecycle management and project and operations management. The classes taught by Dr. Littell focus on new product development, project management, and operations management. Dr. Littell is a certified project management professional as well as a senior certified manufacturing specialist. Dr. Littell may be reached at littellw@ohio.edu

SARA HARTMAN has a PhD in Teaching, Curriculum and Learning from the University of Nebraska-Lincoln and is an assistant professor of early childhood education in the Department of Teacher Education in the Gladys W. and David H. Patton College of Education at Ohio University. Under an early childhood umbrella, Dr. Hartman's research interests are situated within themes pertaining to community/school/university partnerships, rural education, teacher development, and cross-contextual informal learning. Dr. Hartman also has over 11 years' of experience teaching children age's preK-8th grade in a variety of settings and is the co-founder and current board president of the Ohio Valley Museum of Discovery. Dr. Hartman may be reached at hartmans@ohio.edu

AN OPTIMAL MAPPING FRAMEWORK FOR ABET CRITERIA 3(A-K) STUDENT OUTCOMES INTO THE NEWLY PROPOSED (1-7) STUDENT OUTCOMES

Rami J. Haddad, Georgia Southern University; Youakim Kalaani, Georgia Southern University;
Adel El Shahat, Georgia Southern University

Abstract

The Accreditation Board for Engineering and Technology (ABET) is a non-governmental organization that accredits post-secondary degree-granting engineering programs, primarily in the U.S. but around the world as well. The ABET accreditation criteria originally focused mainly on the logistics of engineering education—curriculum, faculty expertise, and facilities. However, these criteria did not effectively address student learning outcomes. Therefore, in 1997, ABET adopted Engineering Criteria 2000 which focused on student learning outcomes and the continuous improvement process. Even though these modified criteria, which included the a-k Criteria 3 student outcomes, helped improve the engineering education process, they still lacked the specificity of student learning outcomes. This made understanding and interpreting the criteria very difficult. ABET has proposed changing Criteria 3 as part of its continuous quality improvement process to help alleviate some of these shortcomings. The proposed modifications changed the infamous eleven student learning outcomes (3-a to 3-k) to only seven students outcomes with significant changes to their content. These drastic changes will certainly trigger a widespread assessment and curricular revamping across all engineering programs. Although the proposed changes to the ABET students outcomes have the potential to improve engineering education, they also might have a negative effect on the educational process if they are not well understood or properly implemented. Therefore, in this paper, the authors propose a novel mapping framework that will help engineering faculty and administrators to map their current student performance indicators and rubrics using the new ABET Criteria 3 student outcomes. This process is intended to ease the transition and minimize the needed changes in the assessment process, which will ensure minimal disruption. In addition, this new mapping will ensure optimization of the faculty time allocated for adapting their assessment efforts.

Introduction

The Accreditation Board for Engineering and Technology (ABET) is a non-governmental organization that accredits post-secondary degree-granting engineering programs all over the world. ABET was established in 1932 as the Engineers' Council for Professional Development (ECPD). The name officially changed to ABET in 1980 and became a federation of 35 professional and technical societies. Since then, ABET has primarily been an accreditation agency for programs within the U.S. However, in 2007, ABET began officially accrediting international programs outside the U.S. The purpose of ABET accreditation is to ensure that essential educational outcomes are addressed within academic programs offering a specific degree, while encouraging innovation and embracing diverse approaches to engineering education rather than promoting conformity. ABET has four commissions that accredit different academic programs as follows:

1. Applied Science Accreditation Commission (ASAC): this commission accredits applied science programs such as Health Physics, Industrial Hygiene, Industrial & Quality Management, Safety Sciences, and Survey/Mapping.
2. Computing Accreditation Commission (CAC): this commission accredits computing-related programs such as Computer Science, Information Systems, and Information Technology.
3. Engineering Accreditation Commission (EAC): this commission accredits engineering programs such as Electrical Engineering, Mechanical Engineering, Civil Engineering, and Manufacturing Engineering.
4. Engineering Technology Accreditation Commission (ETAC): this commission accredits engineering technology programs such as Electrical Engineering Technology, Mechanical Engineering Technology, and Civil Engineering Technology.

Even though all of the commissions share a similar criterion for accreditation, the focus of this paper is on the Engineering Accreditation Commission, since it applies to engineering programs.

ABET Engineering Accreditation Criteria

The purpose of the ABET accreditation criteria is to develop high-quality academic programs that satisfy the needs of their constituents and ensure continuous improvement through a systematic process. The current engineering criteria are referred to as Engineering Criteria 2000 (EC 2000), since these criteria were adopted in 2000. These criteria were based on setting program objectives to address constituents' needs and defining students' learning outcomes that would adhere to the professional practice within the discipline. EC 2000 provided guidelines to help facilitate the assessment process and institute a continuous improvement plan. Engineering Criteria 2000 consists of the following sections:

1- Criterion 1 – Students
2- Criterion 2 – Program Educational Objectives
3- Criterion 3 – Student Outcomes
4- Criterion 4 – Continuous Quality Improvement
5- Criterion 5 – Curriculum
6- Criterion 6 – Faculty
7- Criterion 7 – Facilities
8- Criterion 8 – Support
9- Additional Program Specific Criteria

One of the objectives of revising the ABET accreditation criteria was to harmonize accreditation across all four commissions by streamlining some of the criterion shared by the various commissions. This resulted in two criterion groups: common criteria across commissions and commission-specific criteria (see Table 1).

Table 1. Commission-Common versus Commission-Specific Criteria

Commission-Common Criteria	Commission-Specific Criteria
Criterion 1 – Students	Criterion 3 – Outcomes
Criterion 2 – Program Educational Objectives	Criterion 5 – Curriculum
Criterion 4 – Continuous Improvement	Criterion 6 – Faculty
Criterion 7 – Facilities	Program-Specific Criteria
Criterion 8 – Support	

These criteria are defined as follows [1]:

<u>Criterion 1 – Students</u>

Student performance must be evaluated. Student progress must be monitored to foster success in attaining student outcomes, thereby enabling graduates to attain program educational objectives. Students must be advised regarding curriculum and career matters. The program must have and enforce policies for accepting both new and transfer students, awarding appropriate academic credit for courses taken at other institutions, and awarding appropriate academic credit for work in lieu of courses taken at the institution. The program must have and enforce procedures to ensure and document that students who graduate meet all graduation requirements. (p.3)

<u>Criterion 2 – Program Educational Objectives</u>

The program must have published program educational objectives that are consistent with the mission of the institution, the needs of the program's various constituencies, and these criteria. There must be a documented, systematically utilized, and effective process, involving program constituencies, for the periodic review of these program educational objectives that ensures they remain consistent with the institutional mission, the program's constituents' needs, and these criteria. (p.3)

<u>Criterion 3 – Outcomes</u>

The program must document student outcomes that prepare graduates to attain the program educational objectives. Student outcomes are outcomes (a) through (k) plus any additional outcomes that may be articulated by the program. The (a-k) student outcomes are as follows:

a) an ability to apply knowledge of mathematics, science, and engineering.
b) an ability to design and conduct experiments, as well as to analyze and interpret data.
c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
d) an ability to function on multidisciplinary teams.
e) an ability to identify, formulate, and solve engineering problems.
f) an understanding of professional and ethical responsibility.
g) an ability to communicate effectively.
h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
i) a recognition of the need for, and an ability to engage in life-long learning.
j) a knowledge of contemporary issues.
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. (p.3)

Criterion 4 – Continuous Improvement

The program must regularly use appropriate, documented processes for assessing and evaluating the extent to which the student outcomes are being attained. The results of these evaluations must be systematically utilized as input for the continuous improvement of the program. Other available information may also be used to assist in the continuous improvement of the program. (p.4)

Criterion 5 – Curriculum

The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The faculty must ensure that the program curriculum devotes adequate attention and time to each component, consistent with the outcomes and objectives of the program and institution. The professional component must include:

a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline. Basic sciences are defined as biological, chemical, and physical sciences.
b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.
c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.

Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints. One year is the lesser of 32 semester hours (or equivalent) or one-fourth of the total credits required for graduation. (p.4)

Criterion 6 – Faculty

The program must demonstrate that the faculty members are of sufficient number and they have the competencies to cover all of the curricular areas of the program. There must be sufficient faculty to accommodate adequate levels of student-faculty interaction, student advising and counseling, university service activities, professional development, and interactions with industrial and professional practitioners, as well as employers of students.

The program faculty must have appropriate qualifications and must have and demonstrate sufficient authority to ensure the proper guidance of the program and to develop and implement processes for the evaluation, assessment, and continuing improvement of the program. The overall competence of the faculty may be judged by such factors as education, diversity of backgrounds, engineering experience, teaching effectiveness and experience, ability to communicate, enthusiasm for developing more effective programs, level of scholarship, participation in professional societies, and licensure as Professional Engineers. (pp.4-5)

Criterion 7 – Facilities

Classrooms, offices, laboratories, and associated equipment must be adequate to support attainment of the student outcomes and to provide an atmosphere conducive to learning. Modern tools, equipment, computing resources, and laboratories appropriate to the program must be available, accessible, and systematically maintained and upgraded to enable students to attain the student outcomes and to support program needs. Students must be provided appropriate guidance regarding the use of the tools, equipment, computing resources, and laboratories available to the program.

The library services and the computing and information infrastructure must be adequate to support the scholarly and professional activities of the students and faculty. (p.5)

Criterion 8 – Institutional Support

Institutional support and leadership must be adequate to ensure the quality and continuity of the program. Resources including institutional services, financial support, and staff (both administrative and technical) provided to the program must be adequate to meet program needs. The resources available to the program must be sufficient to attract, retain, and provide for the continued professional development of a qualified faculty. The resources available to the program must be sufficient to acquire, maintain, and operate infrastructures, facilities, and equipment appropriate for the program, and to provide an environment in which student outcomes can be attained. (p.5)

Program-Specific Criteria

Program Criteria for Electrical, Computer, Communications, Telecommunication(s), and Similarly Named Engineering Programs

Lead Society: Institute of Electrical and Electronics Engineers

Cooperating Society for Computer Engineering Programs: CSAB

> These program criteria apply to engineering programs that include "electrical," "electronic(s)," "computer," "communication(s)," "telecommunication(s)," or similar modifiers in their titles. 1. Curriculum The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program. The curriculum must include probability and statistics, including applications appropriate to the program name; mathematics through differential and integral calculus; sciences (defined as biological, chemical, or physical science); and engineering topics (including computing science) necessary to analyze and design complex electrical and electronic devices, software, and systems containing hardware and software components.
>
> The curriculum for programs containing the modifier "electrical," "electronic(s)," "communication(s)," or "telecommunication(s)" in the title must include advanced mathematics, such as differential equations, linear algebra, complex variables, and discrete mathematics.
>
> The curriculum for programs containing the modifier "computer" in the title must include discrete mathematics. The curriculum for programs containing the modifier "communication(s)" or "telecommunication(s)" in the title must include topics in communication theory and systems.
>
> The curriculum for programs containing the modifier "telecommunication(s)" must include design and operation of telecommunication networks for services such as voice, data, image, and video transport. (pp.10-11)

Why ABET Criterion 3 Needed Changing

As part of the ABET continuous improvement process, the idea of revising Criterion 3 was first suggested in 2009, since it had not been revised since it was formulated in the mid-1990s. A taskforce was formed to develop a systematic process to assess, evaluate, and recommend improvements for this criterion. The assigned taskforce developed a step-by-step process for reviewing and revising Criterion 3 as follows:

1. Identify the EAC Criterion 3 constituents and obtain their feedback regarding Criterion 3.
2. Survey the EAC program evaluators to identify Criterion 3 shortcomings.
3. Analyze the reported Criterion 3 shortcomings.
4. Solicit the constituents feedback regarding Criterion 3.
5. Review the constituents' feedback.
6. Conduct an in-depth literature review of the desired attributes of engineers.
7. Develop a revised draft of Criterion 3 students' outcomes for general feedback.

The taskforce's first report in 2010 identified the potential stakeholders as follows:

1. Domestic and non-domestic undergraduate engineering programs.
2. Domestic and non-domestic graduate engineering programs.
3. Employers of the graduates of domestic and non-domestic colleges and universities, including private and public companies that hire engineering graduates, national research laboratories, Government research laboratories, Corps of Engineers, and others.
4. Boards of Professional Engineering Registration.
5. Professional Societies.

In addition, a survey of EAC program evaluators was conducted during the 2010-2011 cycle to identify the appropriateness of the Criterion 3 student outcomes. This survey identified shortcomings in all of the 11 (a-k) student outcomes, with the majority of the programs having the most difficulty with the following outcomes:

- 3-(d) ability to function on multidisciplinary teams.
- 3-(f) understanding of professional and ethical responsibility.
- 3-(h) a broad education to understand engineering solutions in global, economic, environmental, and societal context.

- 3-(i) recognition of the need for and ability to engage in life-long learning.
- 3-(j) knowledge of contemporary issues.

The Criterion 3 taskforce concluded that some of the (a)-(k) components were correlated, broad and vague in scope, or very hard to measure. As a consequence, program evaluators were inconsistent in their interpretation of how well programs were complying with Criterion 3. An outreach effort across all of the constituents was conducted to inform them that Criterion 3 was being reviewed and to solicit suggestions for modifying it. Several responses indicated that the current (a-k) outcomes were not complete and suggested additional outcomes, which increased the total outcomes to 75 (not very practical).

In addition to the feedback received from constituents, the taskforce reviewed national and international reports/ publications that addressed the desired attributes of engineers. These reports/publications came from ABET [1], the American Society of Civil Engineering (ASCE) [2], the American Society of Mechanical Engineering (ASME) [3], the University of Michigan [4], the American Society of Engineering Education (ASEE) [5], the International Engineering Alliance [6,7], the National Academy of Engineering (NAE) [8,9], and the National Society of Professional Engineers (NSPE) [10]. In conclusion, the taskforce presented its findings to the EAC in July of 2013, highlighting the need to revise Criterion 3. The findings were:

- Criterion 3 had the most-reported shortcomings, which necessitated immediate action.
- Within Criterion 3, some student outcomes were difficult to measure.
- The innovation component was not represented properly within the student outcomes.
- Program evaluators were inconsistent in their interpretation of how well programs were complying with Criterion 3.
- Some constituencies reported the need to add more student outcomes.

The EAC Criteria Committee took the taskforce findings of the review process and incorporated them into a revised Criterion 3. In the process of revising Criterion 3, the committee saw the need to revise Criterion 5 as well.

First Proposed Changes to Criteria 3 & 5

In 2014, the EAC Criteria committee presented the first proposed revision to Criteria 3 and 5. The proposed changes to the outcomes are explained as follows:

<u>Student outcome 1</u>: combined student outcomes *e* and *a* as follows:

1) an ability to apply knowledge of mathematics, science, and engineering to identify, formulate, and solve engineering problems. (outcomes *a* + *e*)

<u>Student outcome 2</u>: combined student outcome *c* and *h* as follows:

c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability engineering solutions in a global, economic, environmental, and societal context. (outcomes *c* + *h*)

<u>Then rewritten as follows</u>:

2) an ability to apply both analysis and synthesis in engineering design process, resulting on designs that meet constraints and specifications. Constraints and specifications include societal, economic, environmental, and other factors as appropriate to the design. (rewritten [outcomes *c* + *h*])

<u>Student outcome 3</u>: rewrote student outcome *b*

b) an ability to design and conduct experiments, as well as to analyze and interpret data. (outcome *b*)

<u>Then rewritten as follows</u>:

3) an ability to develop and conduct appropriate experimentation and testing procedures, and to analyze and draw conclusions from data. (rewritten [outcome *b*])

<u>Student outcome 4</u>: modified student outcome *g*

g) an ability to communicate effectively. (outcome *g*)

<u>Then modified as follows</u>:

4) an ability to communicate effectively with a range of audiences through various media. (Modified [outcome *g*])

<u>Student outcome 5</u>: modified student outcome *f*

f) an understanding of professional and ethical responsibility. (outcome *f*)

<u>Then modified as follows</u>:

5) an ability to demonstrate ethical principles in an engineering context. (Modified [outcome *f*])

<u>Student outcome 6</u>: modified student outcome *d*

d) an ability to function in multidisciplinary teams. (outcome *d*)

<u>Then modified as follows</u>:

6) an ability to establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and function effectively on teams. (Modified [outcome *d*])

Furthermore, student outcomes *i* and *j* were completely removed, and outcome *k* was included in Criterion 5.

The revised Criterion 3 student outcomes (a-k) are as follows:

1) An ability to apply knowledge of mathematics, science, and engineering to identify, formulate, and solve engineering problems.
2) An ability to apply both analysis and synthesis in engineering design process, resulting on designs that meet constraints and specifications. Constraints and specifications include societal, economic, environmental, and other factors as appropriate to the design.
3) An ability to develop and conduct appropriate experimentation and testing procedures, and to analyze and draw conclusions from data.
4) An ability to communicate effectively with a range of audiences through various media.
5) An ability to demonstrate ethical principles in an engineering context.
6) An ability to establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and function effectively on teams.

The revised Criterion 5 is presented as follows. The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The curriculum must support attainment of the student outcomes and must include:

a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline. Basic sciences are defined as biological, chemical, and physical sciences.
b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the program and incorporating modern engineering tools. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.
c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.

Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating appropriate engineering standards and multiple constraints. One year is the lesser of 32 semester hours (or equivalent) or one-fourth of the total credits required for graduation.

Second Proposed Changes to Criteria 3 and 5

The first proposed changes to Criteria 3 and 5 were presented to the full EAC in July of 2014 and were posted online at the ABET website to solicit the constituents' feedback. ASEE and other constituents expressed concerns regarding the new proposed changes to Criterion 3 and urged ABET to reconsider or modify some of the proposed changes. Based on the feedback received, the ABET Criteria Committee proposed a second revised draft of Criteria 3 and 5 in addition to a new modification to the preamble. The proposed changes to the outcomes are explained as follows:

Student outcome 7: student outcome 6 became student outcome 7 as follows:

7) an ability to establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and function effectively on teams.

Student outcome 6: brought back a modified student outcome *i*.

i) a recognition of the need for, and an ability to engage in life-long learning.

Then modified as follows:

6) an ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.

The second revision of Criterion 3 student outcomes are presented as follows:

1) an ability to apply knowledge of mathematics, science, and engineering to identify, formulate, and solve engineering problems.
2) an ability to apply both analysis and synthesis in engineering design process, resulting on designs that meet constraints and specifications. Constraints and

specifications include societal, economic, environmental, and other factors as appropriate to the design.

3) an ability to develop and conduct appropriate experimentation and testing procedures, and to analyze and draw conclusions from data.
4) an ability to communicate effectively with a range of audiences through various media.
5) an ability to demonstrate ethical principles in an engineering context.
6) an ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.
7) an ability to establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and function effectively on teams.

The second revision of Criterion 5 is presented as follows. The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The curriculum must support attainment of the student outcomes and must include:

a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline.
b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the program and <u>utilizing</u> modern engineering tools.
c) A broad education component that includes humanities and social sciences, complements the technical content of the curriculum, and is consistent with the program educational objectives

Students must be prepared to enter the professional practice of engineering through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating appropriate engineering standards and multiple constraints. The definitions removed from Criterion 5 were added to the Criteria for Accrediting Engineering Programs preamble. The proposed changes to the Preamble are presented as follows:

<u>Original</u>

These criteria are intended to assure quality and to foster the systematic pursuit of improvement in the quality of engineering education that satisfies the needs of constituencies in a dynamic and competitive environment. It is the responsibility of the institution seeking accreditation of an engineering program to demonstrate clearly that the program meets the following criteria. (p.2)

<u>Modified</u>

These criteria are intended to provide a framework of education that prepares graduate to end the professional practice of engineering who are

i. able to participate in diverse multicultural workplaces;
ii. knowledgeable on topics relevant to their discipline, such as usability, constructability, manufacturability and sustainability; and
iii. cognizant of the global dimensions, risks, uncertainties, and other implications of their engineering solutions.

Further, these criteria are intended to assure quality and to foster the systematic pursuit of improvement in the quality of engineering education that satisfies the needs of constituencies in a dynamic and competitive environment. It is the responsibility of the institution seeking accreditation of an engineering program to demonstrate clearly that the program meets the following criteria. (p.1)

Mapping the Original Criteria 3 to the Newly Proposed Criteria 3

Even though the proposed changes to the ABET student outcomes have the potential to improve engineering education, they might have a negative effect on the educational process if they are not well understood or properly implemented. Therefore, the authors of this current study propose a novel mapping framework that can help engineering faculty and administrators map their current student performance indicators and rubrics using the new ABET Criterion 3. This process is intended to ease the transition and minimize the needed changes in the assessment process to ensure minimal distribution. In addition, this new mapping matrix will ensure an optimal allocation of faculty time to adapt to the new assessment process. This mapping matrix is illustrated in Table 2.

Conclusions

In this paper, the author presented a review of the ABET accreditation criteria and highlighted the continuous improvement process developed over the years. In addition, the findings at every stage of the continuous improvement process were detailed. This process identified significant shortcomings related to Criterion 3 (Student Learning Outcomes), which triggered its first revision. Based on the constituents' feedback, an improved second revision was introduced. Even though the proposed changes to ABET students outcomes have the potential to improve engineering educa-

Table 2. Mapping the Original and the Newly Proposed Criterion 3 Student Outcomes

Newly Proposed Criterion 3 Student Learning Outcomes	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Original Criterion 3 Student Learning Outcomes	Apply knowledge of mathematics, science, and engineering to identify, formulate, and solve engineering problems.	Apply both analysis and synthesis in engineering design process, resulting on designs that meet constraints and specifications. Constraints and specifications include societal, economic, environmental, and other factors as appropriate to the design.	Develop and conduct appropriate experimentation and testing procedures, and to analyze and draw conclusions from data.	Communicate effectively with a range of audiences through various media.	Demonstrate ethical principles in an engineering con-	Recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.	Establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and function effectively on teams.
(a) Apply knowledge of mathematics, science, and engineering.	☑						
(b) Design and conduct experiments, as well as to analyze and interpret data.			☑				
(c) Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.		☑					
(d) Function in multi-disciplinary teams.							☑
(e) Identify, formulate, and solve engineering problems.	☑						
(f) Understand professional and ethical responsibility.					☑		
(g) Communicate effectively.				☑			
(h) Understand the impact of engineering solutions in global, economic, environmental, and societal context.		☑					
(i) Recognize the need for, and engage in life-long learning.						☑	
(j) Knowledge of contemporary issues.	Eliminated in the new Criterion 3						
(k) Use the techniques, skills, and modern engineering tools necessary for engineering practice.	Addressed in the new Criterion 5						

tion, they might have a negative effect on the educational process if they are not well understood or properly implemented. Therefore, a mapping framework was proposed in this paper to help engineering faculty and administrators map their current student outcomes to the new ABET Criteria 3 student outcomes. This process is intended to ease the transition and minimize the needed changes to ensure minimal disruption in the assessment process.

Disclaimer

The bulk of the work presented in this paper was drawn from publicly available ABET documents, ASEE Ad Hoc Committee on ABET EAC Changes Webinar, and the National Academy of Engineering Forum on Proposed Revisions to ABET Engineering Accreditation Commission General Criteria on Student Outcomes and Curriculum (Criteria 3 and 5).

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Biographies

RAMI J. HADDAD is an assistant professor in the Department of Electrical Engineering at Georgia Southern University. He received his BS degree in electronics and telecommunication engineering from the Applied Sciences University, Amman, Jordan; his MS degree in electrical and computer engineering from the University of Minnesota; and his PhD from the University of Akron. He is an IEEE senior member. His research focuses on various aspects of optical fiber communication/networks, broadband networks, multimedia communications, multimedia bandwidth forecasting and engineering education. Dr. Haddad may be reached at rhaddad@georgiasouthern.edu

YOUAKIM KALAANI is an associate professor of electrical engineering in the Department of Electrical Engineering at Georgia Southern University. Dr. Kalaani received his BS degree in electrical engineering from Cleveland State University. Dr. Kalaani graduated from CSU with his MS and doctoral degrees in electrical engineering with a concentration in power systems. Dr. Kalaani is a licensed

professional engineer (PE) and an ABET program evaluator (PA). He is a senior member of IEEE and has research interests in distributed power generations, optimization, and engineering education. Dr. Kalaani may be reached at yalkalaani@georgiasouthern.edu

ADEL EL SHAHAT is an assistant professor of electrical engineering in the Department of Electrical Engineering at Georgia Southern University. He received his BSc in electrical engineering, his MSc in electrical engineering (power and machines), and his PhD (joint supervision) from Zagazig University, Zagazig, Egypt, and The Ohio State University in 1999, 2004, and 2011, respectively. His research interests include power systems, smart grid systems, power electronics, electric machines, renewable energy systems, energy storage, and engineering education. Dr. El Shahat may be reached at aahmed@georgiasouthern.edu

Calculus Eligibility as an At-Risk Predictor for Degree Completion in Undergraduate Engineering

Bradley D. Bowen, Virginia Tech; Roderick A. Hall, Virginia Tech; Jeremy V. Ernst, Virginia Tech

Abstract

Academic readiness and its association with retention and success in engineering has been an ongoing topic of discussion in higher education. Such discussions largely stem from the problematic persistence rates that many colleges and schools of engineering encounter. The ability to retain students in engineering until degree completion has a large research base, although studies over time suggest a variety of factors that contribute to a student's success in engineering. Many of these studies address the entry point or readiness for university mathematics courses as the critical variable; few, however, rely on empirical evidence. In this current study, the authors specifically examined engineering degree completion of calculus-eligible students compared to non-eligible calculus students upon acceptance into the college of engineering as a first-semester freshman. A 10-year span of university student engineering admission and completion data was accessed and analyzed in efforts to provide distinguishing qualities in student preparedness, as they pertain to calculus eligibility as a differentiator. The results of this study show a statistically significant difference in the rate of degree completion for these two groups of students. In this paper, the authors discuss the methodology and results of how being calculus eligible in the first math course taken in an engineering program impacts a student's ability to complete the engineering degree.

Introduction

Retention and success factors are at the foreground of PK-20 educational research. Specifically, experiences [1], opportunities [2], and proficiencies [3, 4] that enhance the prospect of educational and, ultimately, career success for learners is a major focus [5]. According to Levin and Wyckoff [6, 7], "Students are most likely to perform well academically and make sound educational decisions when they understand how their interests and abilities mesh with the characteristics of their chosen fields of study." Many factors, both academic and non-academic, contribute to the successful completion of a college degree. There is a broad research base that has tried to determine the factors and indicators that lead to post-secondary academic success. Many studies have been conducted to determine the factors that may lead to more success in graduating from a university [6-10]. Whether or not a student completes a university degree, particularly on-time degree completion, has a significant impact on student and university resources, such as, but not limited, to money, time, faculty investment, and impact of student advising. Research studies have tried to determine these factors so that universities can make better use of these resources and determine better means for graduating students. From a student's perspective, a study conducted by Meyer and Marx [11] identified that "common themes of non-persisting engineering undergraduates included individual factors (such as poor performance, feeling unprepared for demands of the engineering program, difficulty fitting into engineering) and institutional factors (such as disappointment with engineering advising)."

There is broad teacher and learner research into developing models for determining student retention factors. This research indicates that both academic and non-academic factors determine a student's success in engineering. One study by Levin and Wyckoff [6] reported a model that contained both intellective and non-intellective factors as a means of predicting a student's overall grade point average and ability to persist in an engineering program. It was determined that student success is not dependent on academics only, but included a variety of academic and affective factors. Some of the non-academic factors that have been studied include gender, perception of content area, attitudes, confidence, pre-college experiences, self-efficacy, and career awareness in the field [6-9, 12, 13]. With regard to academic factors that determine a student's success in degree completion, some of the more common factors considered in the research on student retention include, but are not limited to, high school GPA, SAT and ACT scores, college GPA, as well as specific grades in individual courses [9, 10].

Mathematical Ability within Engineering

There are relatively few students declaring an engineering major as a freshman, who successfully graduate with an engineering degree [5, 10, 14]. In an attempt to address the issue of student retention, research on factors that determine general academic success has also been conducted [15]. Research on undergraduate engineering retention has a significant focus on high school and mathematical achievement, primarily high school GPA, SAT math, and ACT math [16, 17].

Mathematical computation ability has become one of the implied criteria for a student's success in degree completion for an engineering program. An anecdotal observation was that lack of student success in first-year mathematics courses is the primary reason for the observed attrition rates in university engineering programs [6, 18-22]. Levin and Wyckoff [6] determined that computational ability is a strong predictor of engineering success, although this study included computational ability within a larger predictive model and did not single out mathematics as a single predictor. By observing end-of-course grades in first-semester math courses, Budny et al. [23] implied that the higher the grade, the higher the likelihood of retention in engineering. However, there is very little empirical evidence to show that mathematical success as a freshman engineering student directly correlates to completion of an engineering degree; and very few studies single out first-year mathematics course success as a predictive factor.

Calculus is typically required for students choosing to enter an engineering field [24]. This course is usually indicated on the suggested plan of study as being required for first-semester freshman. Therefore, due to the implications of not being successful in calculus, studies have been done that try to identify factors for success in mathematics courses. However, current research demonstrates there is a wide variability in the conclusions on the significance of mathematical success to retention in engineering. Zhang et al. [10] and Budny et al. [23] both determined that high school GPA and math SAT scores were positively correlated with graduation rates in engineering. Pyzdrowski et al. [25] looked at factors that determine a student's' successful completion of an entry-level college calculus course. As part of a five-year study, the researchers determined that high school grade point average and higher scores on a calculus readiness assessment were the academic factors that had a significant positive correlation to course performance.

Gardner et al. [26] concluded that the grade freshman engineering students received in their first mathematics course was significantly correlated to their persistence in engineering, but that the actual course they took was not significant and was not found to be directly related to calculus. However, in this current study, the authors defined persistence as being enrolled in engineering one year later, and not by degree completion. In addition, Budny et al. [23] found that the grade engineering students received in their mathematics course in the first semester was an important predictor of retention, even if the math course was not calculus. Moses et al. [5] concluded that the math portion of the SAT was a significant factor in student retention for engineering, but Robinson [20] reported that it was not.

There is an extensive amount of research, with no general consensus, on the specific predictive factors that determine success in engineering. The research demonstrates that a wide variety of factors, both cognitive and affective, influence a student's graduation potential in an engineering program. However, the literature supports a causal assumption that students not eligible to take calculus during their first semester are less likely to graduate in engineering. There is very little research that provides empirical data to support this idea, and very few studies look at calculus as a single independent variable as a predicting factor. The purpose of this current study was to focus on whether or not being eligible to register for calculus as the first math course in a higher education 4-year institution is significant in determining a student’s likelihood of continuing on to degree completion once enrolling in an engineering program as a freshman. Using empirical evidence to determine calculus eligibility as the single predictor of degree completion will contribute a research-proven component to a developing knowledge base. This study was designed to answer the following research question: “Do students have a greater likelihood of graduating with an engineering degree, if they are calculus eligible in their first semester.” To examine the research question, the following hypotheses were developed and tested:

H_0: There is no significant difference in degree completion in the college of engineering for engineering students that are eligible to register for calculus as their first math course compared to the engineering students that are not eligible to register for calculus as their first math course.

H_1: There is a significant difference in degree completion in the college of engineering for engineering students that are eligible to register for calculus as their first math course compared to the engineering students that are not eligible to register for calculus as their first math course.

Methodology

The research team conducted this study from data collected at a single site from a large Midwestern university. Data were collected from registration and records for all students initially accepted into the college of engineering from fall 2005 through fall of 2011. The intent of the study was to focus on the student population that represents traditional admits into the college of engineering as first-semester freshman.

Degree Descriptions

The students at this university have the option of enrolling in nine engineering degrees within six departments. The degrees are: Agricultural Engineering, Biosystems Engineering, Civil and Environmental Engineering, Computer Engineering, Construction Engineering, Electrical Engineering, Industrial Engineering & Management, Manufacturing Engineering, and Mechanical Engineering. There is one construction management degree offered in the Department of Construction Management and Engineering. The students in the construction management department were removed because the research team's intent was to only include degrees that prepared students for a professional engineering (PE) license. Architecture, Landscape Architecture, and Environmental Design were initially part of the college of engineering at the university, but they are no longer designations within engineering. Therefore, the students initially entering the college of engineering, and declaring one of these degrees, were also removed from the data set.

Calculus Eligibility

The single independent variable in the study was calculus eligibility. All nine of the included engineering degrees have a plan of study listing MATH 165, Calculus I, as the recommended mathematics course for the first semester of the students' freshman year. Therefore, the authors defined calculus-eligible as students registering for MATH 165, or a higher-level course, as their first mathematics course. The one exception was MATH 194, which was designated as an independent study. Since the level of mathematics required to complete these credits cannot be determined, students registering for MATH 194 as their first mathematics course were removed from the data set. In some cases, a student may not have a math class during the first semester, yet be registered for MATH 165 or higher the second semester. These students were counted as calculus eligible, because the first math class they registered for was at least MATH 165.

In order to be eligible to register for MATH 165, students must meet certain requirements. These include having a minimum ACT math sub-set score as well as taking the COMPASS Mathematics Test in college algebra and trigonometry or the university's math placement test. If students have an ACT math subset score of 21 or higher, or a composite SAT (math + critical reading) of 990 or higher, they may take the COMPASS mathematics test to determine whether or not they are calculus eligible. On the COMPASS Mathematics Test, students are eligible to register for MATH 165 by receiving a score of 60 or higher on both college algebra and trigonometry. If students have an ACT math subset score of 21 or higher, or an SAT math subset score of 530 or higher, they may take the university mathematics placement test to determine whether or not they are calculus eligible. On the university's mathematics placement test, students receiving a score of 13 or higher on the algebra portion and 10 or higher on the pre-calculus portion are eligible to register for MATH 165. On the university mathematics placement test, students receiving a score of 13 or higher on the algebra portion and between 4 and 9 on the pre-calculus portion are eligible to register for MATH 165, but must also take MATH 105, Trigonometry, as a co-requisite. These students are considered calculus eligible, even if they need to take MATH 105 as a co-requisite.

There are several situations that required the data to be manually cleaned, in regard to calculus-eligible status. Several students took multiple math courses in the same semester. The data sheet reports a different line item for each class. This resulted in those students having multiple line items on the spreadsheet. Therefore, duplicate lines were removed and the only line item remaining was the one indicating the highest level math course. This prevented the students from being counted more than once in the data analysis. Some students did not take a math course the first semester, but registered for calculus the second semester. These students were coded as calculus eligible, because the first course for which they registered was calculus. This study did not include measurements of the students' mathematical abilities, only whether or not they were eligible to register for calculus as their first math course.

Degree Completion

The data set included the original major of each student when they enrolled in the college of engineering as a freshman, and the major they were in at the point of degree completion. The available student data did not include those students having transferred to a different university. All of the initially declared majors were in one of the engineering departments. However, the data set showed a variety of degree-completion majors across campus, since many students, who begin as engineering majors, transferred out of engineering. Some students transferred to a different department, but remained within the college of engineering.

For this study, degree completion was the dependent variable of interest. The research team examined both completion of an engineering degree—"engineering graduates"—and completion of any degree at the university, whether inside or outside the college of engineering—"non-engineering graduates." The combination of both categories was "total graduates." The measure of degree completion was the 6-year graduation rate, since this is a common metric of graduation rate in engineering programs nationwide. Ten years' worth of student admission data resulted in five cohorts of students that could be considered for a 6-year graduation rate. Students who changed majors within the college of engineering were in the category of engineering graduate. The researchers coded these students as engineering graduates.

Statistical Method

To answer the research question, the authors used simple descriptive statistics and binary logistic regression. The binary dependent variable was engineering graduate. The authors also looked at a separate binary model for total graduates. There was a single independent variable—calculus eligibility. The single independent variable in the study was a binary indication of whether the freshmen were, or were not, calculus eligible. Given that the data set was coded using a binary method, and the desired model contained dichotomous variables, the Wald test was appropriate for the statistical analysis [27, 28].

Results

Summary Statistics

After removing the students not having a possible 6-year span to graduate, the data analysis produced 1576 students in the study group. Table 1 shows the raw data for the number of students by their calculus eligibility and degree-completion status. Slightly fewer than half of all students in the sample were eligible to take calculus in their first term (779/1576 = 49.4%).

Table 1. Numbers of Individuals Eligible for the 6-Year Graduation Rate

6-year result	Ineligible	Eligible	Total
Did not graduate	363	159	522
Graduated non-engineering	123	87	210
Graduated engineering	311	533	844
Total	797	779	1,576

In Table 2, the raw numbers from Table 1 were converted to percentages within each category using the total number of students who were calculus eligible and students who were calculus ineligible as the denominator. Table 2 also shows that 53.6% of the students in the sample graduated with an engineering degree within six years. Of those who were calculus eligible, 68.4% graduated with an engineering degree; for those who were calculus ineligible, 39.0% graduated with that degree. Of the calculus-eligible students, 79.6% received some degree from the university, while only 54.5% of calculus-ineligible students graduated from the university with a degree.

Table 2. Percentage of Individuals Eligible for the 6-Year Graduation Rate

6-year result	Ineligible (n=797)	Eligible (n=779)	Total (n=1576)
Did not graduate	45.5%	20.4%	33.1%
Graduated non-engineering	15.5%	11.2%	13.3%
Graduated engineering	39.0%	68.4%	53.6%
Total	100.0%	100.0%	100.0%

Comparing the percentages of students who graduated in engineering as calculus eligible (68.4%) to those not calculus eligible (39.0%) provided valuable information. Figure 1 shows a graphical representation of the population that further illustrates the difference between the two groups of students by calculus eligibility. The two groups had a much different composition in the number of students that had 4-, 5-, and 6-year graduation rates. This figure is an indication that degrees for those who were calculus ineligible generally cost more (for the student and the university) than those with first-semester eligibility.

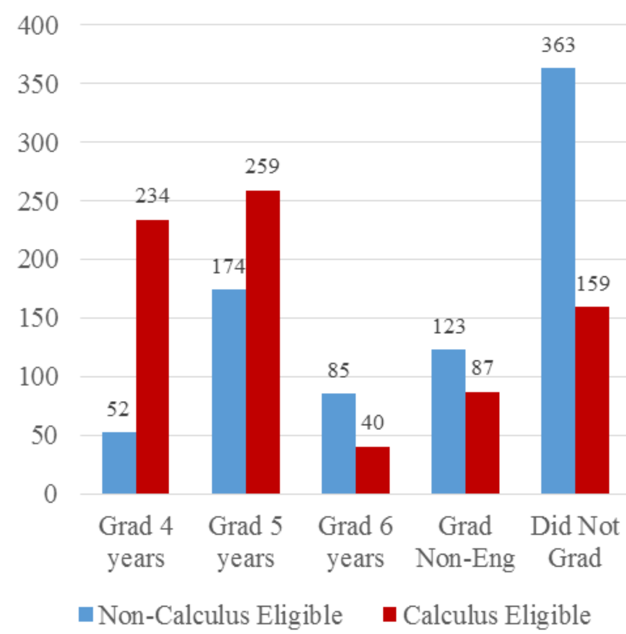

Figure 1. Distribution of Possible Outcomes for All Students in the Study Divided by Calculus Eligibility

Research Question

The research question was whether students entering the university declaring engineering as a major with eligibility to take calculus in their first semester were more likely to complete an engineering degree than those not calculus eligible. Table 3 shows the results of this process, where a student who is calculus eligible as a new admit to the college of engineering is 3.386 times more likely to graduate in engineering within six years than a student that is calculus ineligible. The model had a Wald p-value of < 0.0001 and a Generalized R-Square of 11.28%, indicating that the single variable, calculus eligibility, explained 11.28% of the variation in the model. Table 3 also shows the results of graduation rates for those students finishing their engineering degree in five years or less and within four years.

Table 3. Binary Logistic Regression Results for Calculus-Eligible versus Calculus-Ineligible Students, in Regard to Receipt of an Engineering Degree within Six Years of Matriculation

Odds Ratios	Eligible	Ineligible	Wald p-value	General R-Square (%)
6-year or less	3.386	0.295	< .0001	11.28
5-year or less	4.355	0.230	< .0001	15.78
4-year	6.151	0.163	< .0001	15.41

Note: Ineligible = 1/x of Eligible

It is 4.355 times more likely that an individual who is calculus eligible would graduate within five years than someone who is not calculus eligible. The statistical significance for the 5-year graduation rate had a Wald p-value of < 0.0001, and explained 15.78% of variation in the model. It is approximately 6.15 times more likely that a student who is calculus eligible would graduate within four years than a student who is calculus ineligible. The statistical significance for the 4-year graduation rate had a Wald p-value of <0.0001, and explained 15.41% of the variation in the model.

Conclusions

As demonstrated by the results, there is a statistically significant difference in degree completion when comparing calculus-eligible and non-calculus-eligible students in engineering. Students entering the college of engineering as freshman who are eligible to register for calculus as their first math course are 6.151 times more likely to graduate within four years, 4.355 times more likely to graduate within five years, and 3.386 times more likely to graduate within six years, all with a p-value less than 0.0001. From Table 1, 363 calculus-ineligible students entering into the college of engineering did not complete a degree at all. This was 23.0% (363/1576) of the students included in the study. When examining in more detail the students who completed a degree, the results of the data analysis demonstrated an interesting aspect concerning time to degree completion. These results are shown in Table 4.

Table 4. Mean Years to Degree Completion for All Degree Recipients

	Calculus Eligibility	
	Non-eligible	Eligible
Number of Students	434	620
Years to Completion	4.913	4.458

Students who were calculus ineligible and completed a degree, whether it was in engineering or not, had a time-to-degree completion of approximately one semester (0.455 years) more than those calculus eligible (4.913 years - 4.458 years = 0.455 years). This means that although it is 3.386 times more likely that calculus-eligible students graduate in engineering than those who are calculus ineligible, calculus-ineligible students who do persist to degree completion finish, on average, only one semester later than those who were calculus eligible. This means that calculus-ineligible students need just one semester to make up not being able to take calculus as their first math course. Also, included in this number are the students who transferred out of engineering, but persisted to earn a degree in another major.

Discussion and Implications

This study provides much needed empirical evidence that identifies calculus eligibility as the first math course for a freshman engineer as an at-risk predictor for degree completion. Although the research includes upper-level math preparedness as a factor, there is very little research, particularly empirical results, that singles out calculus' impact. Therefore, this study provides the results necessary to fill the gap in the current research so that researchers and educators can further develop best practices for generating engineering graduates. Several of these practices are identified in previous research, with some of the most critical elements being admission requirements, advising techniques, and resources dedicated to mathematical remediation.

Levin and Wyckoff [6] identified advising as one of the most critical factors in helping students determine their future educational and career trajectory. The results of this study can have a significant impact on advising students who are calculus ineligible compared to those who are calculus eligible. Another critical implication is the remediation process for students needing additional courses to increase their mathematical ability [18, 19, 26], particularly for engineering students not eligible to take calculus in their first semester. If freshman engineering admits are not eligible to register for calculus as their first semester course, then the math credits they need to complete in order to register for calculus do not directly contribute to progression toward degree completion. This means that time and money for both the student and the university are spent in hopes of these students obtaining an engineering degree. However, the results of this study demonstrate that it is only one-third as likely for a calculus-ineligible student to ultimately graduate in engineering compared to a calculus-eligible student.

This study used a single predictor, calculus eligibility, as the only independent variable in the model. Therefore, even though the results demonstrated statistical significance, the Generalized R-Square was 15.41% for 4-year, 15.78% for 5-year, and 11.28% for 6-year graduation rates. The three students who graduated in less than four years were removed from the data set. Occasionally, in a university environment, first-semester freshmen may take a math course at a lower level than what they are eligible to take in order to increase mathematical confidence and foundational understanding of mathematical concepts. It could not be determined from the data set whether or not a student took the highest level math course for which they were eligible; therefore, students were coded strictly on the first math course for which they registered. However, this is not to suggest that concentrated academic intervention prior to the onset of, or during, a post-secondary engineering curriculum could not prove effective in enhancing degree program retention rates; this simply identifies that, through traditional and intact programming, calculus readiness is a variable of substantial magnitude regarding engineering degree completion.

Although the results of this study showed statistical significance, the authors hope to continue to examine specific aspects of the longitudinal data and statistical approaches. Methods to increase the Generalized R-Square will result in a deeper understanding of how the variables in the model explain the results. Now that the overall significance of calculus has been identified, the authors intend to study additional factors, including differences in gender and calculus eligibility toward degree completion, incorporating additional mathematical aspects into the model—such as academic success in various math courses, and determining the math courses for which students are initially eligible to register that can have an impact on degree completion.

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Biographies

BRADLEY D. BOWEN is an assistant professor at Virginia Tech in the School of Education's Integrative STEM Education program. He holds BS and MS degrees in civil engineering and an EdD in technology education. With both high school and industry work experience, Dr. Bowen specializes in professional development and outreach for K-12 students and educators. Dr. Bowen may be reached at bowenb@vt.edu

RODERICK A. HALL has over 25 years of applied higher education experience. He holds a PhD in higher education leadership, an MBA, and a BS in finance. He has been an affiliated faculty member in the Virginia Tech School of Education's Higher Education program since 2009 and currently serves as a faculty fellow in the school's Office of Educational Research and Outreach. Dr. Hall may be reached at roddh@vt.edu

JEREMY V. ERNST is Associate Director for the Virginia Tech School of Education's Office of Educational Research and Outreach and an associate professor of integrative STEM education. He also serves as a research fellow at the Virginia Tech Institute for Creativity Arts and Technology and is an affiliate faculty member of Virginia Tech's Department of Engineering Education. He specializes in research focused on dynamic intervention means for STEM education students categorized as at risk of dropping out of school. Dr. Ernst may be reached at jvernst@vt.edu

AN ENGINEERING DESIGN SEQUENCE INTEGRATED INTO AN ENGINEERING TECHNOLOGY CURRICULUM

Nebil Buyurgan, Missouri State University; Kevin M. Hubbard, Missouri State University; Martin P. Jones, Missouri State University

Abstract

In this paper, the authors describe systematic curriculum development activities in a new Mechanical Engineering Technology degree program at a state university that includes a significant engineering design content. A formal weighted-factor index method was employed in order to determine the amount of design content in the curriculum to remove subjectivity associated with decision making. A sequence of five courses in the curriculum was linked to reinforce key aspects of engineering design in accordance with the Accreditation Board of Engineering and Technology (ABET) requirements and the National Council of Examiners for Engineering and Surveying (NCEES) Fundamentals of Engineering exam knowledge areas. In this sequence of courses, students completed integrative design projects and apply theory to real-world engineering problems. Enterprise skills, including teamwork, professionalism, and recognition of ethical values, were also integrated into the curriculum through these projects. The resulting curriculum is relevant, practical, responsive to the needs of regional industry partners, and provides opportunities for hands-on education, which results in employment-ready graduates.

Designing the Curriculum

The Mechanical Engineering Technology (MET) degree program at Missouri State University was developed in 2013 to address regional industry needs for employment-ready mechanical engineering technologists, and to close the gap between a graduating student and a qualified engineer. Delivering a student-centered, interactive, and cooperative learning environment was the primary purpose during the design of the curriculum. The curriculum was designed using constituent input. Constituents included an industry advisory board and potential employers of graduates. Discussions were conducted with regional industry representatives to determine desired characteristics and employment potential for successful graduates. These discussions resulted in the following conclusions:

- The program should have strong technical content, particularly with regard to engineering design in the area of automation, sensing, and control.
- The enterprise skills component of the program should be maintained throughout a series of courses.
- Mathematical rigor in the degree program should be supported by calculus-based, basic science courses with experimental experience.

In addition, the academic relevance of courses, the mission and vision of the university, modes of delivery, required facilities, and other factors were considered as part of the curriculum design process [1]. Course sequences were developed such that the instructors supply the core material and give students the opportunity to develop their computational and analytical skills, teamwork skills, professionalism, and ethical values. Course content was integrated to encourage students to use, improve, and combine their abilities and talents to design and improve integrated systems of people, technologies, material, information, and equipment within the context of societal and contemporary issues in their practice [2].

Numerous course and curriculum design decisions were made based on the curricular criteria stated previously. Comprehensive engineering design content was incorporated into the curriculum. This engineering design content was embodied as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants [3]. A formal weighted-factor index method was employed during detailed curriculum design in order to ensure an objective decision-making process. This weighted-factor method uses scaled factors for considered alternatives and associated weights to make quantitative objective decisions [4]. The factors upon which these types of decisions are based are often of various orders of magnitude, and are likely to be expressed using different units. In some cases, factors may be difficult to quantify. In cases such as these, factor values may be expressed using a Likert scale for subjective and non-quantitative factors [4]. For objective, easily quantifiable factors, original factor values are used. These values are then normalized through the use of one of Equations (1) and (2):

$$\beta_{ij} = \frac{\text{value of factor } i \text{ for option } j}{\text{largest value of factor } i \text{ among all options}} \tag{1}$$

$$\beta_{ij} = \frac{\text{smallest value of factor } i \text{ among all options}}{\text{value of factor } i \text{ for option } j} \tag{2}$$

where, β_{ij} is scaled factor i for option j.

Equation (1) is employed when large factor values are desirable; Equation (2) is employed when small factor values are desirable. After pertinent factors have been selected, evaluated, and normalized (scaled), a weighted-factor index may be formulated, as in Equation (3):

$$\gamma_j = \sum_{i=1}^{n} W_i \beta_{ij} \tag{3}$$

where, γ_j is the performance index (weighted-factor index) for alternative j; W_i is the importance (weight) associated with scaled factor i; and, n is the number of factors upon which the decision is to be based.

Options exhibiting large weighted-factor index values are superior to options exhibiting small weighted-factor index values. The method was used to decide the amount of engineering design content in the curriculum using the following factors:

- Industrial relevance
- Academic relevance
- Institutional/cultural compatibility
- Accreditation factors
- Adjunct faculty and other required resources

The industrial relevance, academic relevance, institutional/cultural compatibility, and accreditation factors were enumerated using a Likert scale, where a value of five was defined as high and a value of one was defined as low. The adjunct faculty and other required resources factors were enumerated using an estimated required dollar amount. The options evaluated were:

- Option 1—Include engineering design content comprising 5% of the program.
- Option 2—Include engineering design content comprising 10% of the program.
- Option 3—Include engineering design content comprising 15% of the program.
- Option 4—Include engineering design content comprising 20% of the program.

The following variables were employed:

IR_j = the value of industrial relevance for option j
AR_j = the value of academic relevance for option j
ICC_j = the value of institutional/cultural compatibility for option j
ACR_j = the value of desirability (from an accreditation perspective) for option j
AF_j = the value of adjunct faculty and other required resources for option j
β_{IRj} = scaled factor of industrial relevance for option j
β_{ARj} = scaled factor of academic relevance for option j
β_{ICCj} = scaled factor of institutional/cultural compatibility for option j
β_{ACRj} = scaled factor of accreditation desirability for option j
β_{AFj} = scaled factor of adjunct faculty for option j
W_{IR} = weight (importance) assigned to industrial relevance
W_{AR} = weight (importance) assigned to academic relevance
W_{ICC} = weight (importance) assigned to institutional/cultural compatibility
W_{ACR} = weight (importance) assigned to accreditation desirability
W_{AF} = weight (importance) assigned to adjunct faculty

Weights were assigned to each factor in consultation with all departmental faculty as well as approximately twenty industry representatives. The smallest weights were assigned to the institutional/cultural compatibility and academic relevance factors. The highest weighted factors were industrial relevance, desirability, and additional intellectual resources. Table 1 details the Likert scale values and weights assigned to the first four factors as well as intellectual resource funding estimates. Table 2 details the scaled factor values and calculated weighted-factor index values for each option. The scaled values for industrial relevance, academic relevance, institutional/cultural compatibility, and accreditation factors were calculated using Equation (1), whereas the scaled values for the adjunct faculty and other required resources were calculated using Equation (2).

Table 1. Likert Scale Values and Weights

	Likert Scale Values (Weights)				Resource Funding
Option	IR (0.25)	AR (0.15)	ICC (0.10)	ACR (0.25)	AF (0.25)
1	2	3	2	2	\$15,000
2	4	4	3	3	\$7,500
3	3	3	4	3	\$15,000
4	3	2	2	2	\$22,500

Option 2 (10% engineering design content) was determined to be the superior alternative, followed by Option 3 (15% engineering design content), Option 1 (5% engineering design content), and Option 4 (20% engineering design content). It should be noted that the conclusion drawn from these calculations may be changed through the assignment of different weight values.

Table 2. Scaled Factor Values

	Scaled Factor Values					Index Values
Option	β_{IR}	β_{AR}	β_{ICC}	β_{ACR}	β_{AF}	γ_j
1	0.50	0.75	0.50	0.67	0.50	0.58
2	1.00	1.00	0.75	1.00	1.00	0.98
3	0.75	0.75	1.00	1.00	0.50	0.65
4	0.75	0.50	0.50	0.67	0.33	0.56

ABET requirements were also considered when developing this curriculum. ABET requires MET programs to prepare graduates with knowledge, problem-solving ability, and hands-on skills to enter careers in the design, installation, manufacturing, testing, evaluation, technical sales, or maintenance of mechanical systems [2]. Therefore, supervised in-class activities, laboratory exercises, and term projects were created for courses to support lectures and assignments to enable student learning. ABET accreditation standards also emphasize major design experiences based on student course work. The following ABET Student Learning Objectives (SLO) were adopted and addressed in these courses [2].

A. An ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly defined engineering technology activities.
B. An ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies.
C. An ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes.
D. An ability to design systems, components, or processes for broadly defined engineering technology problems appropriate to program educational objectives.
E. An ability to function effectively as a member or leader on a technical team.
F. An ability to identify, analyze, and solve broadly defined engineering technology problems.
G. An ability to apply written, oral, and graphical communication in both technical and nontechnical environments; and an ability to identify and use appropriate technical literature.
H. An understanding of the need for and an ability to engage in self-directed continuing professional development.
I. An understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity.
J. A knowledge of the impact of engineering technology solutions in a societal and global context.
K. A commitment to quality, timeliness, and continuous improvement.

Developing Course Content

Incorporating different phases of engineering design, a sequence of five courses was designed that would focus on scoping, generating, evaluating, and realizing ideas [5]. The engineering design content covered in these five courses was about 10% of the program curriculum. The same formal weighted-factor index method was employed in order to determine the proportion of the course material dedicated to engineering design. In addition to the aforementioned factors, course prerequisite structure was also considered and the courses were aligned based on the guidelines of the NCEES Fundamentals of Engineering Mechanical exam knowledge areas [6]. These knowledge areas included electricity and magnetism, material properties and processing, and mechanical design and analysis.

The sequence starts with a freshmen-level introductory course, entitled "Introduction to Engineering Design," that introduces fundamental concepts of engineering design, including computational methods, the design process, and communication techniques. The sequence continues with a sophomore-level second course, "Electrical Circuits," that concentrates on electrical circuit design by providing in-depth knowledge of theory, analysis, and applications of electrical circuits. The third course in the sequence is a junior-level course, entitled "Mechanical Design and Analysis," that focuses on traditional manufacturing process design and mechanical design to introduce engineering materials and mechanisms design into the curriculum. The fourth course, "Product Design and Conceptualization," is also a junior-level course that introduces prototyping, designing for different considerations, robust design, design economics, as well as patents and intellectual property.

Students complete an integrative design project in each course and apply the presented theory to real-world engineering problems. Course deliverables include written reports with detailed design data and analysis, group and individual presentations, and one or more working, physical product prototypes. Projects are also used to introduce enterprise soft skills, including various levels of communication, teamwork, professionalism, and recognizing ethical values. The sequence is finalized by a senior-level capstone "Senior Design" course that requires student participation in interdisciplinary teams to bring a product from conceptual design through manufacture. Activities include detailed design, material selection, cost estimation, process planning, schedule and production requirements planning, distribution systems design, software planning and implementation, and product fabrication [7].

The Introduction to Engineering Design course is the introductory course in which students are introduced to engineering design. The course emphasizes iterative decision making in the engineering design and development process and introduces fundamental steps of product design, including developing mission statements, identifying and analyzing customer needs, establishing product specifications, as well as generating and evaluating product concepts. The course also includes an engineering graphics component, where students learn the basic principles, techniques, and practices for developing drawings in a CAD environment. Students in this class also work on a semester-long course project in teams of four to complete a conceptual design of a product. The goal of the project is to learn and apply principles and methods of the design process to improve teamwork skills and to appreciate the inherent multidisciplinary nature of engineering design. The Introduction to Engineering Design course objectives and ABET SLOs addressed by each objective are as follows [7]:

1. Comprehend the structure of the engineering design process, and develop and evaluate a conceptual product using this process (ABET SLO F, SLO H).
2. Understand drafting standards and the conventions of 2D engineering drawings, and communicate the development of a conceptual product (ABET SLO D, SLO G).
3. Comprehend the syntax of engineering design tools to analyze engineering technology problems (ABET SLO D, SLO F, SLO G).
4. Function effectively on a team (ABET SLO E, SLO K).

The Electrical Circuits course focuses on electrical components and automation in the design of a component or product. Feasibility, cost analysis, and usability of electrical components and automation are introduced to students to help them make decisions on what to automate when designing a product. The course content also includes analysis of different off-the-shelf electrical systems to investigate sensor/actuator combinations, matching voltages, amperages, etc. Students also experience what is available for purchase and how to perform a make-or-buy analysis for electrical components and automation. The course is supported by laboratory hours, where students build components and conduct experiments individually and in project groups. The Electrical Circuits course objectives and their ABET SLOs include [7]:

1. Demonstrate an understanding of Ohm's law, Kirchhoff's laws, and the power rule (ABET SLO B, SLO C, SLO G).
2. Design basic series, parallel, and combination circuits (ABET SLO B, SLO D).
3. Use simulation software to predict the response of complex circuits to various inputs (ABET SLO A, SLO G).
4. Design circuit noise filters and power distribution systems (ABET SLO B, SLO D).
5. Find steady-state, DC, and transient solutions for AC/DC circuits composed of resistors, capacitors, inductors, op amps, and other electrical components (ABET SLO A, SLO D).

The Mechanical Design and Analysis course introduces simultaneous engineering concepts, where both product design and in-service performance as well as product fabrication and assembly are considered during the design phase of project inception. Students perform a semester-long integrative design project that synthesizes the above concepts. The Mechanical Design and Analysis course objectives and ABET SLO’s addressed by each are [7]:

1. Perform rational material selection, including the evaluation of material performance indices and the use of material selection charts (ABET SLO A, SLO D, SLO F).
2. Perform rational manufacturing process selection (ABET SLO B, SLO D, SLO F).
3. Perform tolerance assignment activities using both traditional and statistically based tolerancing methods (ABET SLO B, SLO D, SLO F).
4. Synthesize the above skills in order to perform design-for-manufacture tasks (ABET SLO A, SLO B, SLO D).

The Product Design and Conceptualization course introduces detailed engineering design considerations in an entrepreneurial environment, including product architecture, design for environment, design for manufacturing, quality aspects in engineering design, design economics and cost estimation, and industrial design as well as patents and intellectual property issues. The course also has a prototyping component, where students employ different prototyping tools and technologies, and develop a physical prototype of a product. This component is coupled with a course project, where each project team designs and analyzes a product based on the considerations noted above. The Product Design and Conceptualization course objectives and their ABET SLOs include [7]:

1. Comprehend the structure of the product design and development process. Build, evaluate, and test a physical product using this process (ABET SLO C, SLO D, SLO K).
2. Communicate a design and its analysis (written, oral, and graphical forms) (ABET SLO G, SLO K)
3. Function effectively on a team (ABET SLO E, SLO I).

The Senior Design course incorporates an integrated capstone design experience that is based on work performed by the student in all prior technical courses. The course is a critical component of the curriculum and provides the student with a comprehensive opportunity to utilize the skills and abilities obtained through the MET program core material as well as the incorporated engineering design content. In addition, this course represents a major design experience, which typically consists of an industrial project, and allows students to demonstrate their ability to work in teams to design, develop, implement, and improve integrated products and systems. The Senior Design course is not a lecture-based course; instead, each team has designated (weekly) meeting times with the course instructor, where they review their project accomplishments, next steps, and any potential roadblocks. There are several milestones during the semester for preliminary and final reports as well as formal and informal presentations. Since this course is used to perform a summative ABET SLO assessment for the program, course objectives are not individually mapped to SLOs. Course objectives include [7]:

1. Integrate product/process/tooling design skills acquired from previous course to design and fabricate a prototype of a complex product involving some automation component.
2. Synthesize analytical market, production system, cost estimation evaluation and design skills acquired from previous course to perform commercialization activities associated with the product of item 1 noted above.
3. Conduct effective meetings, organize and participate in effective teams, and develop and deliver effective reports and presentations.
4. Appreciate the necessity for the continual upgrade of engineering and technical knowledge.

Figure 1 presents the engineering design content in each course is linked to each of the other courses using course objectives determined by the program's faculty.

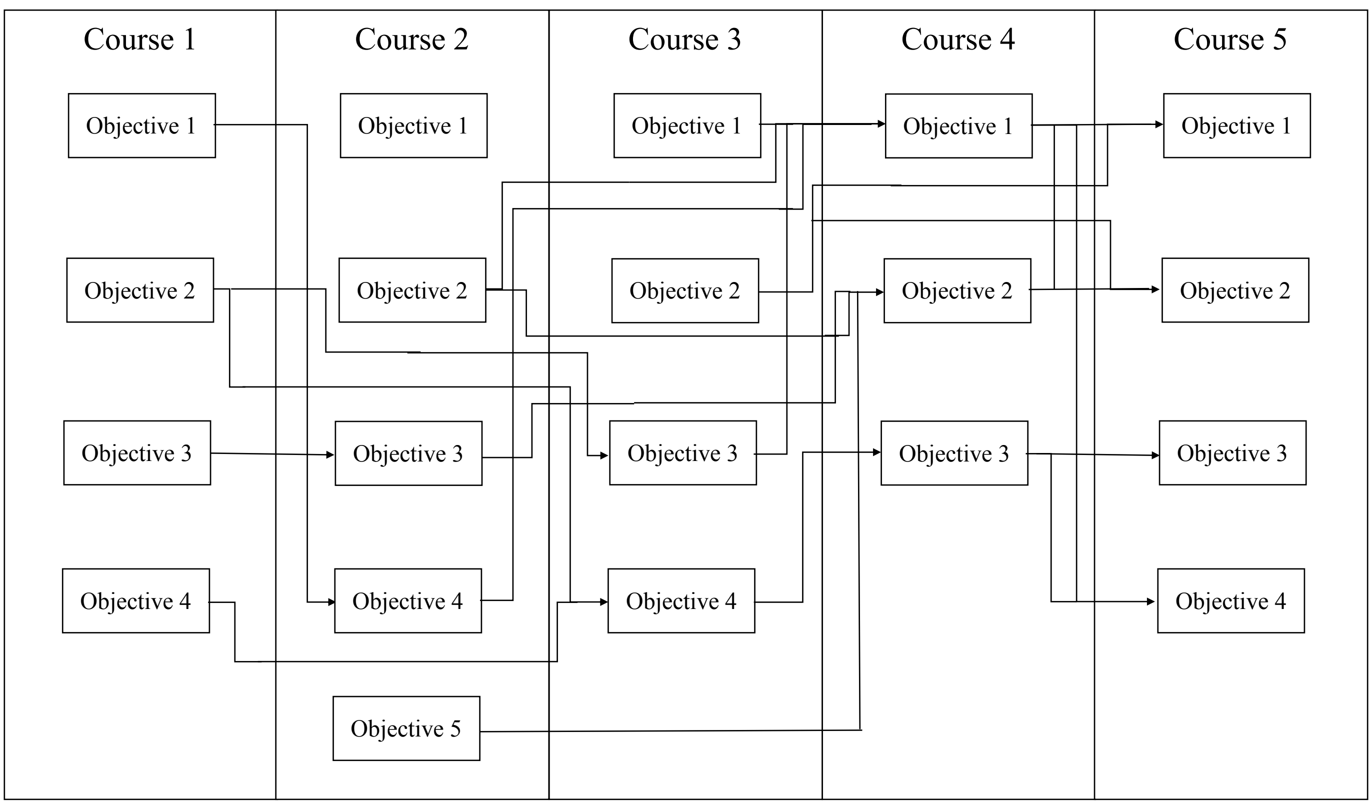

Figure 1. Generalized Course Objectives in the Sequence

A Sample Project

Integration of industrial projects into engineering curricula has been suggested by other educators [8]. In this section, an industrial project from a sample Senior Design course is presented with some level of detail. The project was executed by a group of MET students as a culminating engineering design project, where they utilized engineering design tools, methods, and concepts. The project was assigned to a team with the following problem statement:

> Typical roundness testers available to industry today are often capable of measuring much tighter tolerances than are necessarily required by the products that are measured by these devices. Also, these roundness testers are very expensive (~$30,000) for a machine that is capable of measuring workparts up to 15.75 inches. However, approximately 85% of all manufactured cylindrical workparts are under 2.00 inches in diameter.

As the team of engineers, you will identify a need in the market for a lower cost Form Measurement Device for Circular Geometries (FMD-CG), which will be capable of measuring five geometric dimensioning and tolerancing (GD&T) controls, including total runout, circular runout, circularity (roundness), concentricity, and cylindricity. Then, you will design and fabricate a prototype FMD-CG within the required specifications.

A set of comprehensive analyses must be conducted for the product and its production system that include market share analysis, material and process selection, and production system and site requirements. A facility layout study also has to be conducted, which should account for all necessary machinery and production operations to produce the designed product. Additionally, a capacity plan has to be developed and personnel requirements have to be identified for the production. A selling price for the product has to be identified to yield an attractive potential profit under a high-demand scenario.

In the first stage of the project, students developed a project mission statement and a product function statement, which were introduced in the Introduction to Engineering Design course. These statements mainly included product description, primary and secondary markets, major project assumptions and constraints, stakeholders, project life, and current state of the market. Students conducted an extensive market analysis to develop a background on the product and its current use in industry. The team focused on product demand and market opportunities. An extensive customer needs assessment and market forecast analysis utilizing mathematical and statistical tools and methods was conducted. This content was introduced in both the Introduction to Engineering Design and Product Design and Conceptualization courses.

In the conceptual design stage, students conducted a functional decomposition analysis for the product and developed product specifications. A major consideration was given in the product requirements to measure the aforementioned five GD&T controls. Functional requirements for electronic systems, hardware requirements, and software requirements were determined, considering the economic feasibility of FMD-CG. Since the product had to contain electrical and mechanical components as well as a software controller, students utilized tools and techniques that were introduced in the Electrical Circuits and Mechanical Design and Analysis courses for functional decomposition analysis and product specification.

Multiple concepts were designed with different capabilities. Cost-estimation tools were used to calculate a detailed cost for each concept. In addition, material selection, process selection, make-versus-buy decisions, tooling, and a detailed inspection plan were developed for the concepts. These tools and methods were introduced in the Mechanical Design and Analysis and Product Design and Conceptualization courses in the curriculum. Developed concepts were evaluated based on these criteria, with the most promising concept selected for further consideration. The team then designed and fabricated a detailed prototype of the selected concept in a laboratory environment.

The next stage included production system and product design for production as well as site selection for FMD-CG. Manufacturing and assembly techniques and requirements as well as needed equipment were considered in developing a production system. A detailed analysis of available manufacturing machines, assembly, and inspection equipment was conducted for production operations. Similar to the prototype design stage, material selection, process selection, make-versus-buy decisions, tooling, and a detailed inspection plan were developed for the production system. In addition, facility requirements were identified for a facility layout study. A capacity planning analysis was performed based on the required production levels.

Site selection for the production facility and a profit analysis were the last stages in the project. The team considered ten cities in eight states for the location of the production facility, based on the available Department of Labor statistics. In addition, a general cost estimation was done for potential sites. Considering the results of the analysis, expected product life, estimated market share, and annual inflation rate, a price for the product was determined to yield a certain net profit for the operations.

Conclusions

In this paper, the authors report a series of course content and curriculum development activities in the Mechanical Engineering Technology (MET) program at Missouri State University to incorporate comprehensive engineering design content. A formal weighted-factor index method was used to determine the amount of design content in the curriculum in order to remove subjectivity associated with decision making. A series of five courses was then developed to introduce engineering design. Courses in this series not only introduced different aspects of engineering design, but also assessed and evaluated student learning in individual or team projects. Projects were also utilized to provide opportunities for students to improve their enterprise skills. Courses and their engineering design content were linked to each other using course objectives developed under ABET SLOs and NCEES Fundamentals of Engineering exam knowledge areas. In addition to individual and team projects in courses, students participated in a culminating capstone project in the Senior Design course, where they utilized engineering design tools, methods, and concepts.

Future enhancement will include incorporating the design of a product for one of the nationwide student competitions into the courses. For example, Baja SAE student competition includes designing and building a single-seat, all-terrain, off-road vehicle that should survive on rough terrains. This engineering design project activity can be merged into the courses so that students would design and fabricate different components of the vehicle in different courses in the MET curriculum. Also, since this curriculum was developed in consultation with regional industry partners, the alignment of ABET and regional accreditation standards [9] will be further considered.

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Biographies

NEBIL BUYURGAN is an associate professor of technology and construction management at Missouri State University. He earned his BS degree (Industrial Engineering, 1998) from Istanbul Technical University, Turkey; MS (Engineering Management, 2000) from the University of Missouri – Rolla; and, PhD from the University of Missouri – Rolla (Engineering Management, 2004). Dr. Buyurgan is currently teaching at Missouri State University. His research interests include optimization of logistics operations in manufacturing, healthcare, military and retail, and supply chain management. Dr. Buyurgan may be reached at NebilBuyurgan@MissouriState.edu

KEVIN M. HUBBARD is an assistant professor of technology and construction management at Missouri State University. He earned his BS degree (Aerospace Engineering, 1991), MS (Engineering Management, 1993), and PhD (Engineering Management, 1996) degrees from the University of Missouri – Rolla. Dr. Hubbard is currently teaching at Missouri State University. His research interests include automation and device control, manufacturing systems, de-

vice design, and process optimization. Dr. Hubbard may be reached at KHubbard@MissouriState.edu

MARTIN P. JONES is an associate professor of technology and construction management at Missouri State University. He earned his BS degree (Physics, 1981) from the University of Maryland Baltimore County; MS degree (Materials Science & Engineering, 1984) from the Johns Hopkins University; and, PhD (Materials Science & Engineering, 1987) from the Johns Hopkins University. Dr. Jones is currently teaching at Missouri State University. His research interests include scanner technology, nondestructive evaluation, manufacturing processes, and quality assurance. Dr. Jones may be reached at MartinJones@MissouriState.edu

Incorporating PID Control Methods into a Line-Following Robotic Car

Yuqiu You, Ohio University

Abstract

Proportional-integral-derivative (PID) is control widely used control method in industrial applications. System performance varies based on the physical settings of the system and configuration of the controller. Line-following robotic cars are typical classroom projects for students to study and practice control method implementation. In this paper, the author describes a project for applying PID control to such cars. Also presented are the hardware components for PID control implementation, the programming method used, parameter configuration, and evaluation of system performance.

Introduction

The proportional-integral-derivative (PID) control method is the most widely applied control algorithm in industry. This is due to the PID control method's strong capability in various industry control operations and its simplified function in configuration and operation. A PID controller's operation can be described as to read the feedback signal from a sensor and compute the output for the system actuator by calculating proportional, integral, and derivative responses [1]. However, system performance varies, based on the physical setting of the system and configuration of the controller. Line-following robotic cars are typical classroom projects for students to study and practice control method implementation. The line-following function could be realized through various control methods and programming mechanisms. The PID control method provides a straightforward method for students to learn and practice controller configuration. The controller design and configuration can be evaluated directly from system performance.

The purpose of this project was to implement the PID control method on a line-following robotic car for a robotics interfacing course within an engineering technology program. The line-following robotic car was built with two DC motors, an H-bridge SN754410 chip, a set of eight infrared sensors, an ultrasonic sensor, an Arduino UNO controller, and a car frame. The line-following function is realized by implementing the PID control to ensure quick response, accuracy, and flexibility of the system. Digital signals from eight infrared sensors are read to the Arduino controller, and are used as feedback input for the PID controller to determine the current position of the car and compute the output based on errors. The output variable is used to control the speed and direction of the two DC motors through the SN754410 H-bridge. The configuration of the PID controller gains for P, I, and D, can optimize the control system to get an ideal response to line-following performance.

System Overview

The line-following car was built with a car frame, an Arduino UNO controller, a SN754410 H-bridge driver, two DC motors, a set of eight infrared (IR) sensors, and an ultrasonic sensor. Figure 1 provides a system overview. Figure 2 shows a picture of the completed car.

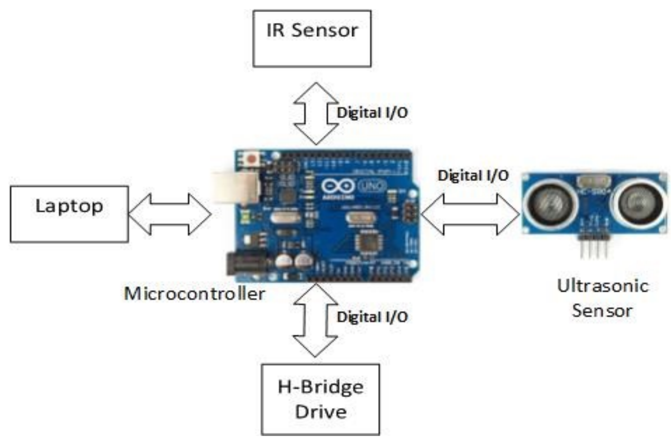

Figure 1. Major Components of the System

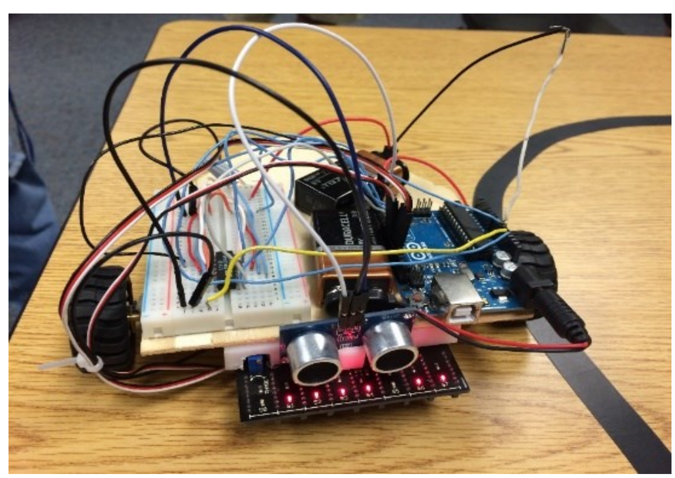

Figure 2. A Completed Line-Following Robotic Car

The Arduino UNO controller is a microcontroller board based on the ATmega328P. It provides fourteen digital input/output pins, six of which can be used as PWM outputs. It also has six analog inputs, a 16-MHz quartz crystal, a USB connection, a power jack, and a reset button. The SN754410 is a quadruple high-current H driver to enable speed and direction control of DC motors by supplying bidirectional electrical currents. It can be used to control four DC motors with four pairs of driver pins. Each pair of driver pins is enabled by one EN pin assigned for them. When the enable pin receives a HIGH signal, the associated driver pins are enabled and the outputs from these pins become active. When the EN pin receives a LOW signal, these drivers will be disabled and their outputs turned off. With the control signals from the Arduino controller, each pair of drivers can make a full H-bridge reversible drive for one DC motor [2]. Figure 3 shows the wiring connections for the SN754410 H-bridge drive.

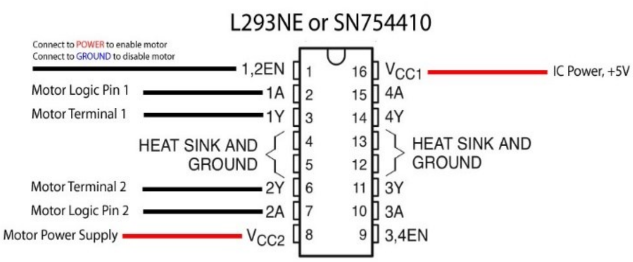

Figure 3. Wiring Connections for the SN754410

The ultrasonic sensor used in this project was an HC-SR04 ultrasonic ranging sensor. The purpose of using this sensor was to detect any possible obstacle in front of the robot in order to avoid collision. The sensor contained an ultrasonic transmitter, a receiver, and a control circuit. This sensor had a measurement distance ranging from 2 cm to 400 cm, and the accuracy was 3 mm. There were four pins to be connected on the HC-SR04 sensor to the microcontroller: Vcc (power), trig (trigger), echo (receiver), and GND (ground). Figure 4 presents a picture of the sensor.

Figure 4. The HC-SR04 Ultrasonic Sensor

The ultrasonic sensor sends out a high-frequency sound pulse and then measures how long it takes for the echo to return. The time difference between sending and receiving the sound pulse multiplies the speed of sound (341 meters per second), which can be used to determine the distance that the sound traveled. Since the sound wave has traveled to the object and back, the actual value of the distance of the object from the sensor can be determined by dividing this number by two. The infrared sensor set is a long board with eight IR sensors configured for reading digital bits. There are LEDs on the top of the board to indicate the digital reading of each infrared sensor. The line-following function was programmed based on this 8-bit reading of reflectance from this sensor set to the microcontroller. Figure 5 shows a component diagram of this infrared sensor set.

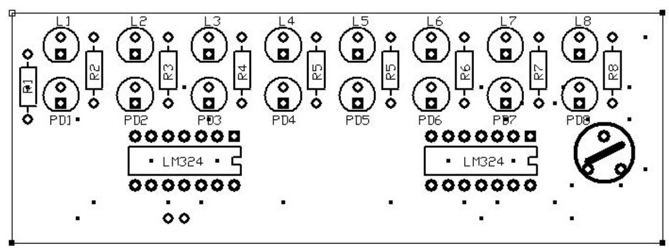

Figure 5. The Infrared Sensor Set

PID Theory and Programming

Figure 6 shows a typical closed-loop control system containing several critical components: the process variable, sensor feedback, the set point, the compensator, the actuator output, and the system to be controlled.

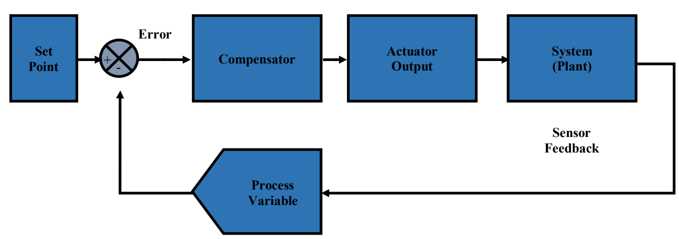

Figure 6. A Closed-Loop Control System

The system is the physical setup to be controlled by the controller, such as the robotic car in this project. The process variable is the system parameter to be controlled. In this case, the process variable was the speed and direction of the two DC motors of the car. The sensor feedback is the signal sent from the sensor based on the current sensor measurement. For the car in this project, the ultrasonic sensor and the IR sensor set were used to provide the feedback signals. The set point is the desired value for the process variable. The set point for the line-following control function was the correct position of the car relative to the line. At any given moment, the controlled process variable was measured by sensors and compared with the set point, and the difference was recorded as an error. The control algorithm programmed in the controller, the compensator, would then use the error to calculate the desired output to send to the actuator. In this case, the actuators were the two DC motors.

The PID algorithm is a classic and robust control algorithm that determines the actuator output by summing the three different components derived from the error to reduce the response time and minimize the steady state error. These three components include the proportional component, the integral component, and the derivative component [3]. Figure 7 shows a block diagram of a basic PID controller. In this diagram, all three components are indicated.

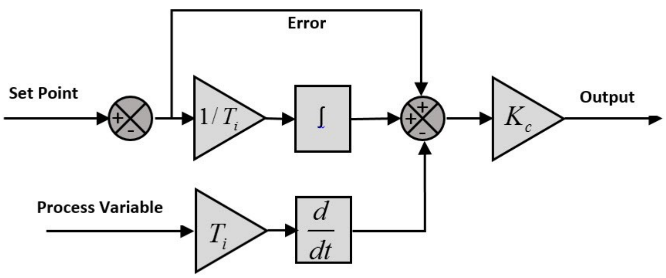

Figure 7. A Basic PID Control Algorithm

The PID algorithm can also be described using the format of Equation (1):

$$u(t) = ke(t) + k_i \int_0^t e(t)dt + k_d \frac{de}{dt} \quad (1)$$

where, $u(t)$ is the output signal to the actuator and $e(t)$ is the control error.

As explained in earlier, the error is the difference between the process variable and the set point at any given moment. The control parameters are proportional gain, k, the integral gain, $k_{i,}$ and the derivative gain, k_d. As illustrated in Equation (1), the proportional component acts on the current value of the error. The output calculated based on this component will be proportional to the input error. The error will decrease with an increasing gain value, though the system could become more oscillatory and unstable. The integral component does an integration by adding the errors over time (the time durations could be determined in programming) and calculating an output that is proportional to the overall error. Therefore, the integral output increases continuously. The system can respond to errors faster for larger integral gains, but the system also becomes unstable. The derivative component calculates the output signal based on the difference in changes over time. The output signal is proportional to the derivative summation. Therefore, the output signal will decrease if the process variable is increasing rapidly. If the derivative time increases, the response speed of the control system will increase and the system will respond strongly to error signals. However, in situations where the feedback signals are noisy, or the control loop is slow, the derivative component could make the entire system unstable. Thus, determining the set point and the three different PID gains for the controller was critical for the line-following performance of the robotic car in this project.

In this project, the PID control of the car was different from traditional PID control implementation, because the sensor feedback signals were digital signals instead of analog. The process variable of this control system was the position of the car. The set point was the target value of the process variable. In this case, it was the position at which the line was located—at the center line between two wheels of the car. Figure 7 shows how the position values were calculated by multiplying the digital signal from each infrared sensor (0 or 1) with the position weight assigned to each of the sensors. At any given moment, the error was calculated by comparing the current position value of the car with the predetermined correct position value. This error would then be used to determine the output signal to drive the two DC motors by the PID algorithm in the Arduino controller. Figure 8 shows that all three PID components were used in the programming.

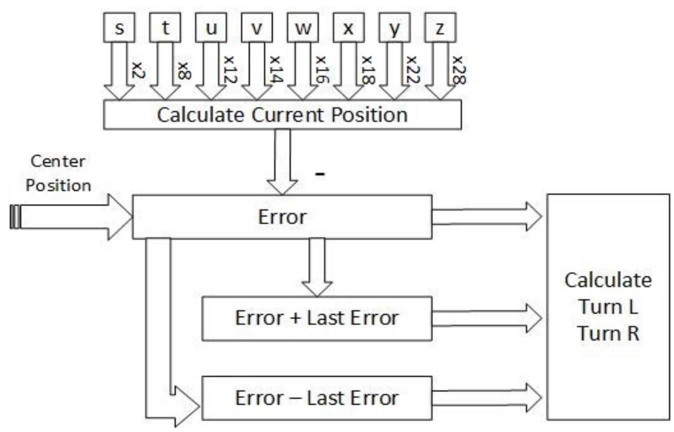

Figure 8. Control Variable Calculation

The digital signals from the infrared sensors that were evenly mounted at the front part of the car were assigned a position weight valve that ranged from 2 to 28, according to their locations (see again Figure 7). Then, the calculated values, based on the digital signals from the set of infrared sensors, could be used to determine the actual location of the car relative to the line. As the car followed the line, sensor signals were constantly changing according to the car's location relative to the line.

The position error was calculated using Equation (2):

$$TotalPosition = s + t + u + v + w + x + y + z$$
$$Position = \frac{2s + 8t + 12u + 14v + 16w + 18x + 22y + 28z}{TotalPosition} \quad (2)$$

A calculated position value of 15 means that the car was perfectly following the line, which means that the line was at the center of the car. Whenever the car deviated from the line, the position error was calculated: $Error = Position - CorrectPosition$. The PID method was used to calculate the speed (number of turns) for both the left and right motors, based on this position error. The speed calculation used K_p, K_i, and K_d, the proportional component, the integral component, and the derivative component, for smooth and accurate control of following the line. Here is a description of the control function of the program for the PID method:

```
// Using PID calculate the error.
void PID(int Kp, int Ki, int Kd)
{
 //---PID---
 // For P
 error = error;
 /*

 // For I

 // For remains the same integral error value. (error = last error)
 integral += error;
 integral = constrain(integral,0,100);

 /* For error of position changed.
 E.g. last time error is 2, now error is one. */
 if ( error != lastError )
 { /*
 // For +ve position value.
 if ( Position > 0 )
 {
 if ( Position > lastPosition ) // away from the line.
 integral = 0;
 else
 integral = 0; // towards to the line.
 }

 // For -ve position value.
 else if ( Position < 0 )
 {
 if ( Position < lastPosition ) // away from the line.
 integral = 0;
 else
 integral = 0; // towards to the line.
 }
  // For position value is 0.
 else*/
 integral = 0;
 }
  // For D
 derivative = error - lastError;

 // Sum of the error of PID + encoder
 turn = (Kp*error + Ki*integral/10 + Kd*derivative);
 turn = constrain(turn,-100,100);

 // Make turn1 & turn2 only have -ve value.
 // +turn1 & -turn2
 turn_L = constrain(turn,-100,0);
 turn_R = constrain(turn,0,100);
}
```

Line-Following Implementation

When implementing a line-following function, the controller scanned signals from the infrared sensors every 15 ms, and the calculated control signals were sent to the DC motor drives to make adjustments to the speeds of both wheels. Figure 9 shows a line-following robotic car in operation. Comparing the line-following performance of the car, based on the PID method and one with a case-selection programming method, the performance of the car with PID controller runs much smoother. And the PID controller responds to deviations much quicker, such that the car never runs away from the line. The car with this case-selection programming method encounters few unexpected stops during the line-following test. In case of running away from the line, the PID controller was programmed to stop the car if no line has been detected for three seconds. However, this situation never happened during the testing of the PID line-following robotic car.

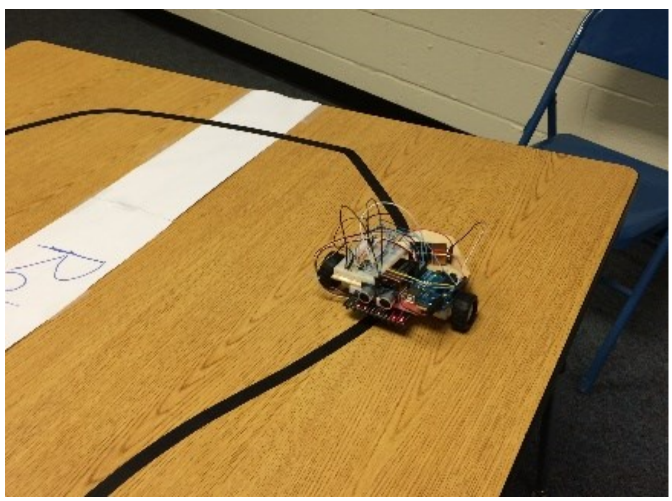

Figure 9. Line-Following Implementation

Here is a demonstration of the complete coding of the controller:

```
#define LSensor1 3
#define LSensor2 4
#define LSensor3 6
#define LSensor4 5
#define LSensor5 A0
#define LSensor6 A1
#define LSensor7 A2
#define LSensor8 A3
#define motor_L1 13
#define motor_R1 7
#define pwm1 9
#define pwm2 10
#define motor_L2 12
#define motor_R2 11

const int pingPin = A4;

// Variable for line checking
int Position=0, correctPosition=15, totalPosition=0;
int error=0, lastError=0;
int timerZero=0, timeStopA=0, timeStopB=0;

// Variable for PID
int integral=0;
int derivative=0;
int turn,turn_L,turn_R;
// debounce time for line checking
unsigned long timeLSensor, debounceDelayLSensor = 15;

// Setup the robot to move 15s.
unsigned long timeToStop = 1500000;

void setup()
{
 pinMode(LSensor1,INPUT);
 pinMode(LSensor2,INPUT);
 pinMode(LSensor3,INPUT);
 pinMode(LSensor4,INPUT);
 pinMode(LSensor5,INPUT);
 pinMode(LSensor6,INPUT);
 pinMode(LSensor7,INPUT);
 pinMode(LSensor8,INPUT);
 pinMode(motor_L1,OUTPUT);
 pinMode(motor_R1,OUTPUT);
 pinMode(pwm1,OUTPUT);
 pinMode(pwm2,OUTPUT);
 pinMode(motor_L2,OUTPUT);
 pinMode(motor_R2,OUTPUT);

 timeLSensor = millis();

 Serial.begin(9600);
 Serial.println("SETUP DONE");
}

void loop()
{
 long duration, inches, cm;

 pinMode(pingPin, OUTPUT);
 digitalWrite(pingPin, LOW);
 delayMicroseconds(2);
 digitalWrite(pingPin, HIGH);
 delayMicroseconds(5);
 digitalWrite(pingPin, LOW);

 pinMode(pingPin, INPUT);
 duration = pulseIn(pingPin, HIGH);

 // convert the time into a distance
 inches = microsecondsToInches(duration);
 cm = microsecondsToCentimeters(duration);

 Serial.print(inches);
 Serial.print("in, ");
 Serial.print(cm);
 Serial.print("cm");
 Serial.println();

 delay(100);
 // Stop the motor after 15s.
 if (inches < 5)
 {

 StopRun();
 }

 else
 lineFollower(5,10,30,50,50);

}

// Make the robot track to the line.
void lineFollower(int kKp, int kKi, int kKd, int speed_L, int speed_R)
{

 lineCheck();
 PID(kKp,kKi,kKd);
 go_Straight(speed_L + turn_L, speed_R - turn_R);
}


// Check the position of the robot.
void lineCheck()
{

 // Check line for every 15ms.
 if ( millis() - timeLSensor >= debounceDelayLSensor )
 {

 // Take the reading of 8 line IR sensor.
 int s = digitalRead(LSensor1);
 int t = digitalRead(LSensor2);
 int u = digitalRead(LSensor3);
 int v = digitalRead(LSensor4);
 int w = digitalRead(LSensor5);
 int x = digitalRead(LSensor6);
 int y = digitalRead(LSensor7);
 int z = digitalRead(LSensor8);

 // Calculate the position of the robot.
 lastError = error;

 // When no line is detected.
 if (s==0 && t==0 && u==0 && v==0 && w==0 && x==0 && y==0
&& z==0)
 {

 // Setup a timer
 if (timeStopB > 0)
```

```
timerZero += timeStopA - timeStopB ;

timeStopB = timeStopA;
timeStopA = millis();


if (lastError == 0)
{
/*StopRun();
Serial.println("***Stop***");*/
Position = 15;
}

// Robot stops when it away from line more than 3 second.
while (timerZero > 1500)
StopRun();

}

// When line is detected.
else
{
// Reset the timer when it detects the line again.
timerZero=0, timeStopA=0, timeStopB=0;

// Calculate the position of the robot.
totalPosition = s + t + u + v + w + x + y + z;

Position = ( 2*s + 8*t + 12*u + 14*v + 16*w + 18*x + 22*y + 28*z ) /
totalPosition;
}

timeLSensor = millis();
error = Position - correctPosition;

/*
Serial.print("Position : "); // Show value of position on laptop.
Serial.println(Position);
Serial.print("lastError : "); // Show value of last position on laptop.
Serial.println(lastError);
Serial.print("error : "); // Show value of error on laptop.
Serial.println(error);
Serial.println("------------");*/
}
}

// Using PID calculate the error.
void PID(int Kp, int Ki, int Kd)
{
//---PID---
// For P
error = error;
/*
Serial.print(Position), Serial.print(" ; ");
Serial.print(error), Serial.print(" ; ");
Serial.print(lastError), Serial.println(" ; ");
*/

// For I

// For remains the same integral error value. (error = last error)
integral += error;
integral = constrain(integral,0,100);

/* For error of position changed.
E.g. last time error is 2, now error is one. */
if ( error != lastError )
{ /*
// For +ve position value.
if ( Position > 0 )
{
if ( Position > lastPosition ) // away from the line.
integral = 0;

else
integral = 0; // towards to the line.
}

// For -ve position value.
else if ( Position < 0 )
{
if ( Position < lastPosition ) // away from the line.
integral = 0;

else
integral = 0; // towards to the line.
}

// For position value is 0.
else*/
integral = 0;
}

// For D
derivative = error - lastError;

/*
Serial.print("Error_P : "); // Show value of error P on laptop.
Serial.println(error);
Serial.print("Error_I : "); // Show value of error I on laptop.
Serial.println(integral);
Serial.print("Error_D : "); // Show value of error D on laptop.
Serial.println(derivative);
*/

// Sum of the error of PID + encoder
turn = (Kp*error + Ki*integral/10 + Kd*derivative);
turn = constrain(turn,-100,100);

// Make turn1 & turn2 only have -ve value.
// +turn1 & -turn2
turn_L = constrain(turn,-100,0);
turn_R = constrain(turn,0,100);

/*
Serial.print("Turn : "); // Show value of turn on laptop.
Serial.println(turn);
Serial.println(" ");
*/
}

// Robot go straight.
void go_Straight(int speedL, int speedR)
{

Forward();

speedL = speed_Map(speedL);
speedR = speed_Map(speedR);
analogWrite(pwm1,speedL);
analogWrite(pwm2,speedR);
/*
Serial.println("*Go Straight*");
Serial.print("pwm1 : ");
```

```
 Serial.println(speedL);
 Serial.print("pwm2 : ");
 Serial.println(speedR);*/
}

// Robot reverse.
void go_Reverse(int speedL, int speedR)
{
 Backward();

 speedL = speed_Map(speedL);
 speedR = speed_Map(speedR);
 analogWrite(pwm1,speedL);
 analogWrite(pwm2,speedR);
 /*
 Serial.println("*Go Backward*");
 Serial.print("pwm1 : ");
 Serial.println(speedL);
 Serial.print("pwm2 : ");
 Serial.println(speedR);*/
}

// Robot rotate left.
void self_Rotate_Left(int speedL, int speedR)
{
 rotateLeft();

 speedL = speed_Map(speedL);
 speedR = speed_Map(speedR);
 analogWrite(pwm1,speedL);
 analogWrite(pwm2,speedR);
 /*
 Serial.println("*Rotate Left*");
 Serial.print("pwm1 : ");
 Serial.println(speedL);
 Serial.print("pwm2 : ");
 Serial.println(speedR);*/
}

// Robot rotate right.
void self_Rotate_Right(int speedL, int speedR)
{
 rotateRight();

 speedL = speed_Map(speedL);
 speedR = speed_Map(speedR);
 analogWrite(pwm1,speedL);
 analogWrite(pwm2,speedR);
 /*
 Serial.println("*Rotate Right*");
 Serial.print("pwm1 : ");
 Serial.println(speedL);
 Serial.print("pwm2 : ");
 Serial.println(speedR);*/
}

// Convert speed in the range of 0 - 100.
int speed_Map(int speed_Motor)
{
 speed_Motor = constrain(speed_Motor,0,255);
 speed_Motor = map(speed_Motor,0,60 ,0,255);

 return speed_Motor;
}
// Setup the motors to move forward.
void Forward()
{
 digitalWrite(motor_L1,HIGH); // Move forward.
 digitalWrite(motor_R1,LOW);
 digitalWrite(motor_L2,LOW); // Move forward.
 digitalWrite(motor_R2,HIGH);
}
// Setup the motors to move backward.
void Backward()
{
 digitalWrite(motor_L1,LOW); // Move backward.
 digitalWrite(motor_R1,HIGH);
 digitalWrite(motor_L2,HIGH); // Move backward.
 digitalWrite(motor_R2,LOW);
// Setup motors to turn left.
void rotateLeft()
{
 digitalWrite(motor_L1,LOW); // Move backward.
 digitalWrite(motor_R1,HIGH);
 digitalWrite(motor_L2,LOW); // Move forward.
 digitalWrite(motor_R2,HIGH);
}
// Setup motors to turn right.
void rotateRight()
{
 digitalWrite(motor_L1,HIGH); // Move forward.
 digitalWrite(motor_R1,LOW);
 digitalWrite(motor_L2,HIGH); // Move backward.
 digitalWrite(motor_R2,LOW);
}

// Stop the motors.
void StopRun()
{
 digitalWrite(pwm1,0);
 digitalWrite(pwm2,0);
 delay(100);

 digitalWrite(motor_L1,LOW);
 digitalWrite(motor_R1,LOW);
 digitalWrite(motor_L2,LOW);
 digitalWrite(motor_R2,LOW);
}
long microsecondsToInches(long microseconds)
{

 return microseconds / 74 / 2;
}
long microsecondsToCentimeters(long microseconds)
{
 return microseconds / 29 / 2;
}
```

Conclusions

This PID line-following robotic car project was implemented in order to introduce classic control methods in courses in the Manufacturing Engineering and Technology program. Students gain a better understanding of this control theory by applying it in a hands-on project, not simply a theoretical analysis. The parameter settings for the PID control provide a real case for students to learn the critical impact of these parameters on the response time, accuracy, and stability status of the controlled motion.

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Biographies

YUQIU YOU is an associate professor of engineering technology and management at Ohio University. She earned her BE degree from HuaZhong University of Science and Technology in China, MS from Morehead State University, and PhD (Technology Management, 2006) from Indiana State University. Dr. You is currently teaching at Ohio University. Her research interests include computer-integrated manufacturing, automation control, and remote control systems. Dr. You may be reached at youy@ohio.edu

A Project-Based and Mini-Competition Driven Microcontroller Course Design for Engineering Technology Programs

Jin Zhu, University of Northern Iowa

Abstract

In this paper, the author presents strategies and considerations for the development of a microprocessor/microcontroller course, including both hardware and software selection as well as course structure and organization. Various options in development hardware kits and integrated development environment (IDE) are compared. With rapid advancements in technology, it is important that students are given the opportunities to learn the portable knowledge and skills in an environment similar to that in industry. It requires that students not only learn the knowledge but also can apply what they learn to solve practical problems creatively. A microcontroller course designed with the integration of project-based learning and robot competition is described. Results showed that combined half-semester-long projects combined with in-class mini-competitions can engage and motive students to learn effectively.

Introduction

A microprocessor or microcontroller course is typically a required technical core course in electrical engineering technology or computer engineering technology programs because microprocessors are fundamental to these areas. Different strategies and factors need to be considered when implementing or updating a microprocessor or microcontroller course curriculum. There are also various challenges that engineering/engineering technology education faces.

In the Preface of the book, *Rethinking Engineering Education—the CDIO Approach*, the former MIT president Charles Vest stated, "Students, for example, are driven by passion, curiosity, engagement, and dreams," and educators should focus on the environment and context in which students learn, and provide authentic situations to which they are exposed [1]. The Conceive-Design-Implement-Operate (CDIO) initiative for engineering education was thus proposed. One of the most important teaching strategies that CDIO embraces is so-called experiential learning. In his work, Kolb [2] discussed the six characteristics of experiential learning, including that "learning is best conceived as a process, that is, concepts are derived from and continuously modified by experience," and "learning is a continuous process grounded in experience, that is, learners enter the learning situation with more or less articulate ideas about the topic at hand, some of which may be misconceptions" [1]. CDIO is aimed at promoting a curriculum organized around mutually supportive courses rich with student-designed and -build test projects. The model is more focused on the product lifecycle with the four steps of conceive, design, implement, and operate. The CDIO model has been implemented at MIT and over 100 universities within the fields of aerospace, applied physics, electrical engineering, and mechanical engineering [3-5].

Some critical issues in engineering education include courses that do not provide sufficient integration of various engineering and technical topics [6]. One teaching strategy proven to be effective in addressing these issues is project-based learning (PBL). PBL is a teaching method in which students apply knowledge and gain skills by working for an extended period of time to investigate and solve an engaging and complex problem or challenge. In general, project tasks are similar to professional practice, and usually it takes a longer period of time to solve than that for problem-based learning problems. Project work is more focused to the application of knowledge in solving problems in reality, as indicated by Mills and Treagust [6]. The comparison by Edström and Kolmos [7] shows that there are many similarities between PBL and CDIO—both emphasize on the development of professional skills through learning processes.

Curricula that integrate with project-based learning have been reported and implemented at different universities. In the literature, project-based learning has been used in computer engineering curricular design [8] and throughout different courses in electronic systems curricula and electrical and computer engineering curricula [9, 10]. Case studies have been done to enhance PBL in computer architecture courses [11]. The PBL method has also been used in microcontroller and embedded system course design [12, 13]. It has been reported that PBL can influence students' attitudes towards STEM education and improve the effectiveness of learning [14]. Nagvajara and Kizirian [15] studied student needs for project-based course design.

Background Information

Embedded systems are widely used nowadays in both industry and our daily lives It is going to be even more widespread because of the emerging Internet of Things (IoT). Understanding the fundamentals of microcontroller-based system design and implementation is critical to computer and electrical engineering technology students. The Microcontroller Applications course is one of the technical core courses of the Electrical Engineering Technology program at the University of Northern Iowa. The course was taught using an 8-bit BASIC Stamp microcontroller from Parallax that programs using PBASIC language (a language similar to BASIC). The system was adopted more than 14 years ago, because of the ease with which the PBASIC programming language can be learned. However, BASIC is not commonly used in embedded systems design in industry. According to the VDC survey of embedded developers in 2010, about 82% of projects were developed using the C programming language [16]. C remains the most widely used embedded programming language for embedded systems, with compilers available for almost every microprocessor and microcontroller on the market [17]. In order to make the microcontroller course a better match with industrial practice, it was decided to change the course format to use C programming instead of PBASIC during the update of the course in 2014. A proper MCU development board also needed to be selected for the course.

Course Development

There are many microcontroller options available for educational purposes. More and more low-cost microprocessor or microcontroller development boards with powerful functions are emerging onto the market. There are plenty, if not too many, of choices that are available when choosing a microprocessor to carry out the teaching activities, from 8-bit to 32-bit microprocessors, Harvard architecture to Van Norman architecture, Reduced Instruction Set Computer (RISC) to Complex Instruction Set Computer (CISC) architecture, to mention a few. Some popular options for microcontroller courses are listed below:

- 8-bit PIC microcontrollers from Microchip
- 8-bit AVR core-based microcontrollers from Atmel (acquired by Microchip in 2016)
- 16-bit MSP430 ultra low-power microcontrollers from Texas Instruments
- 8-bit 8051 core-based microcontrollers
- 8-bit 68HC12 series microcontroller from Freescale (acquired by NXP in 2015)
- ARM Cortex-M series 32-bit microcontrollers

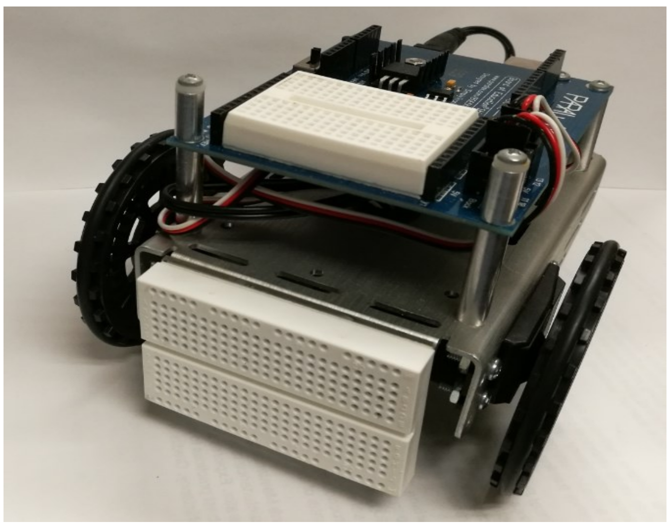
According to IC Insights' 2014 McClean report [18], 4/8-bit MCUs regained their position as the largest unit-volume category in 2013 over 16-bit microcontrollers. It was further predicted that the 4/8-bit MCU would retain its position as the largest unit-volume category in microcontrollers until 2018. Although 32-bit MCUs have gained more and more popularity since 2010, due to smartphones, 8-bit MCUs are still widely used. Considering that this is an introductory-level microcontroller course, an 8-bit microcontroller is more appropriate. The Arduino UNO board was eventually selected after comparison and evaluation. Not only is Arduino UNO one of the most popular MCU development boards, it is also inexpensive ($22-$34 per board), widely availability, and there is an active Arduino community using it [19]. The microcontroller used on the Arduino UNO board is an ATMega328P, an 8-bit AVR core-based MCU from Atmel (now Microchip). Although the Arduino board itself may not be the popular choice for industry, the AVR 8-bit microcontrollers are one of the most popular and efficient 8-bit MCUs.

The AVR microcontrollers use RISC architecture and are widely used in industry, especially in automotive applications and the Internet of Things (IoT). What students learn in the course, using the low-cost Arduino boards, can be easily applied to other AVR core-based microcontrollers. In addition, the Arduino software is free and available for different computer operating systems. Once the Arduino UNO development board is chosen, the organization of the course and pedagogy need to be determined. Based on results found in previous studies [8-15], it was decided to develop this as a project-based course. Robotics competitions have long been used to increase student engagement in both secondary schools and universities [20-22]. Robotics competitions may bring in excitement, motivate student learning, and also provide opportunities for students applying their creativity. With that in mind, a robotics mini-competition was integrated into the microcontroller course. The course content and hands-on labs provide necessary fundamentals to the students, but a student also has to determine his/her design in hardware and software, implement it, and participate in the competition at the end of the semester.

Hardware and Software

The robotics platform used was the BoE-bot robot from Parallax [23]. Figure 1 shows both the Arduino board (UNO rev3) and robotics platform used for the course. One additional prototyping board was added to the front of the robotic platform so that students could add components of their own design. A robot included two servo motors, and the shield board provided four servo motor interfaces.

(a) Arduino Board



(b) Robotics Platform

Figure 1. Robotics Platform Used for the Course

The Arduino integrated development environment (IDE) can be downloaded free and is available in Windows, Linux, and iOS systems [24], which allows students to work on projects on their own computers outside of class. It is worth noting that the debugging function of the Arduino IDE is very limited. Atmel provides a much more powerful IDE for AVR core-based MCUs, the Atmel Studio (version 7 is the latest) [25]. The disadvantages of Atmel Studio are that the system is much more complicated, only available in Windows, and requires a large space on the computer. However, the Arduino IDE provides built-in C/C++ software functions that are easy to use, very user friendly, and easy to pick up for anyone with little programming experience. Built-in functions such as pinMode(), digitalWrite(), and digitalRead (), are specific for Arduino boards. If another microcontroller platform is used, those functions are not available. Therefore, learning based solely on the Arduino functions is not really useful and cannot be easily transferred to other MCU platforms.

As mentioned previously, C is the most widely used programming language for embedded systems [12]. With that in mind, this course focused on learning ANSI C programming using the Arduino board and IDE. C programming for I/O access, ADC, and Timer/Counter and Interrupts and Serial communications are discussed in generic terms whenever possible. The Arduino built-in functions are avoided unless the functions are necessary, but the implementation and corresponding contents have not been covered yet. The purpose is to let students learn ANSI C programming as much as possible so that what they learn in the course is portable.

Course Objectives and Structure

The microcontroller application course objectives include:

- Understand the architecture and organization of microprocessors and microcomputers.
- Learn to program in standard ANSI C for microcontrollers for various applications.
- Learn basic assembly language codes and structure of data used in microcontrollers.
- Develop specifications for a microprocessor-based device, while considering tradeoffs among features and functionality, cost and availability of materials, and time for construction.
- Learn the communication and interfacing modes between microprocessors and external devices to deal with both digital and analog signals.
- Gain hands-on experience in the development and troubleshooting of microcontroller systems and interfacing with external devices needed to implement a microprocessor application.
- Be aware of recent developments in microprocessor and microcontroller technology.
- Be able to apply creativity and the knowledge learned to design a microcontroller-based system for control, data acquisition, or robotics applications.
- Be able to deliver an effective presentation explaining the design, construction, and functionality of a microcontroller-based system.

The course was organized around the robotics mini-competition. The course included lectures and class demonstrations, but relied heavily on hands-on lab experiments. A robot platform was used to engage the students and motivate them to participate. Assessments included the final competition, a project report, and open-book in-class exams that included programming problems. The class would meet two 2-hour sessions per week.

Robotics Mini-Competition

Each student is given a kit that includes both the Arduino board and the robot at the beginning of the semester. Students use the kit throughout the semester. Each student is required to complete the design project. The purpose of the project is for testing the students' overall skills in microcontroller-based system design and programming. Students need to apply what they learned in the course to complete the project: an autonomous robot that is capable of exploring a course. In the last class of the semester, students present and demonstrate the completed robot on the course. The mini-competition tasks and requirements are given to students in mid-semester. The students have around eight weeks to complete the project. The mini-competition is held during the last week of the semester. Originally, the robot arena was 4 ft x 5 ft but later adjusted to 4 ft x 8ft. Figure 2 shows an example of the course.

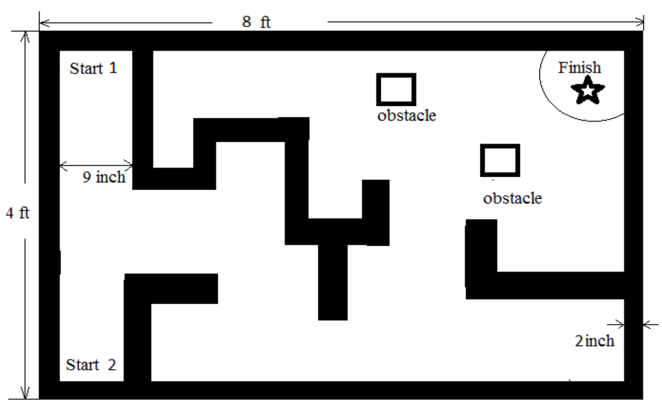


Figure 2. Robot Competition Arena

The border of the course was made of electrical tape or black tempera paint at least two inches wide. The robot could be placed randomly at one of the starting points without advance notification. Each robot has a maximum of three minutes to explore the course and complete the task. The tasks are as follows:

1. The robot should be placed at the starting point and wait until a pushbutton (start button) is pressed. After the pushbutton is pressed, a piezo speaker beeps to indicate the start of the robot's actions.
2. The robot should be aware of the boundaries of the course and not go beyond the borders.
3. The robot should be able to follow the path given at the start of the course (and not cross the black tape).
4. There are several obstacles placed on the course and the robot should be able to avoid them.
5. One light bulb is placed at the end of the course. Once the robot reaches the finish area, it must stop moving and indicate so by beeping.

Students are encouraged to be creative in solving the problem effectively and completing tasks. Students are allowed to modify the hardware and use additional components in addition to those used in labs, as long as they do not damage the robot. The project is evaluated based on both the creativity of the design, the effectiveness of the implementation, and the quality of the final report. The first three students completing all of the tasks within the shortest time (but within the 3-minute limit) are awarded extra credit towards to the final grade. The more tasks a robot complements within the allotted three minutes, the more effective the implementation. Each student is allowed at least two runs, and the better score of the two runs is counted as the project functionality score. The final technical report is evaluated based on both technical content, writing, and organization. The final report should describe the project entirely, and include at least the following:

1. Project objectives and description of the robot's function;
2. A description of the design process and methodology;
3. A diagram showing the implemented system architecture
4. Parts list and schematics/wiring diagram for hardware;
5. All software with appropriate comments (including flowchart for the main program);
6. A description of the test process and any major bugs/ issues found;
7. Conclusions for the project and any lessons learned from the project;
8. A list of references, if applicable.

Hands-On Laboratory Experiments

The microcontroller course consists of seven labs that are carefully aligned with course lectures and, at the same time, to prepare students for the project.

Lab 1: Introduction to the Arduino IDE and BOE-Bot Shield Kit

This lab was designed to familiarize students with Arduino UNO, the robotics kit, and Arduino IDE. Instructions are provided so that students can upload the programs to the

Arduino UNO board, calibrate and test the continuous rotation servo motors, and test the basic navigation function of the robot.

Lab 2: Program Using ANSI C and Additional Robot Navigation Functions

This lab was designed to have students learn to program the Arduino board using standard C functions. They must test the operations of the pointer, address access and bitwise operators, and learn to troubleshoot and debug the program. Students also learn to control robot navigation for ramping up/down and turning using user-defined functions.

Lab 3: GPIO Access and Robot Tactile Navigation

This lab was designed to have students learn how to control digital input/outputs of the MCU (i.e., general-purpose input/output GPIO using ANSI C). Students also learn how to control robot navigation using tactile switches and interfaces with seven-segment LEDs using GPIOs.

Lab 4: Timers/Counters

This lab helps students understand the operations of timers/counters. ATmega328P has a total of three timers/counters, including one 16-bit Timer/Counter and two 8-bit Timer/Counters. Students learn to program timers to generate time delays and pulse-width-modulated (PWM) waveforms that can be used in many control applications. It also covers how to use counters to count external events.

Lab 5: Interfacing to Analog Inputs

In this lab, students learn how to interface with analog inputs using the internal ADC module via port C in the ATmega328P. Students must configure the ADC registers using ANSI C to interface with temperature sensors and phototransistors/photo-resisters and use the sensor data to guide the robot's navigation.

Lab 6: Interrupt and Robot Navigation Using Infrared Receivers

This lab was designed the help students understand the operation of interrupts in MCUs and learn to program interrupts in ANSI C. Students also learn to use infrared LEDs and receivers to guide the robot's navigation.

Lab 7: Serial Communication—LCD Control Using USART

This lab was intended to help students understand the operation of serial communications. Students learn to program Universal Synchronous and Asynchronous Receiver/Transmitters (USART) using ANSI C to interface with an LCD and update sensor data in the LCD.

Feedback and Discussion

The overall feedback from students with regards to the robotic mini-competition-based microcontroller course was positive. According the course survey conducted in the fall of 2014, 83.3% of students agreed or strongly agreed that they were motivated to work on the class project, since the robotics project was interesting. Another 87.5% of the students suggested that they liked the idea of the class project, while the rest remained neutral. When asked if they would recommend this or a similar topic for the class project next year, 92% of the students replied positively or strongly positively, while 8% remained neutral.

Student outcome analyses in the fall 2014 and 2015 semesters revealed one prerequisite issue for the course. Originally, the microcontroller applications course had two prerequisites: one digital electronics course and one programming language course that could be either Visual Basic or C/C++. It turns out that the Visual Basic course did not prepare students sufficiently for the microcontroller course, according to the assessment results using performance indicators. Students usually struggle in the microcontroller course if they have not taken C/C++ before the course. Students who used Visual Basic to satisfy the programming language course prerequisite had an average grade of 1.7 (out of 4), while the students who took C/C++ to satisfy the prerequisite had an average grade of 3.1. After the discovery, the prerequisite of Visual Basic was removed and students had to take C/C++ to satisfy the programming language prerequisite, which became effective starting in the fall of 2017.

Conclusions

For computer and electrical engineering technology students, it is important to understand the fundamentals of microcontrollers. Many students have found the MCU course helpful in applying microcontrollers in real-life applications and using microcontrollers for their senior design projects. Project-based curriculum design and robotic competition can be used together to create a positive learning experience. Both approaches can be seen as compatible and mutually reinforcing. The integrated method cannot only engage and motivate students, but also promote creativity by allowing students to solve problems and tasks effectively. By adopting platforms and programming languages commonly used in industry, and focusing on the portable knowledge and skills learning, a microcontroller course can be more valuable to the students and may also help them understand the importance of self-learning and continuous improvement.

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Biography

JIN ZHU is an associate professor of electrical engineering technology at the University of Northern Iowa. She earned her PhD (electrical engineering, 2005) from the New Jersey Institute of Technology. Her research interests include wireless networks, ambient energy harvesting, Internet of Things (IoT), embedded systems, and robotics. Dr. Zhu may be reached at jin.zhu@uni.edu

Evaluation of Outcomes and Senior Design Projects from a Capstone Design Course

Mohan Devgun, State University of New York College at Buffalo; David J. Kukulka, State University of New York College at Buffalo

Abstract

Students studying in the Mechanical Engineering Technology (MET) Program at the State University of New York College at Buffalo (BSC) are required to complete a senior design project. The Accreditation Board for Engineering and Technology (ABET) has developed a set of learning outcomes that are used to guide faculty in assessing the effectiveness of academic programs. The MET program at BSC uses the ABET criteria to assess student learning in the MET courses. These learning objectives help students understand the general skills and knowledge that they will later demonstrate in order to complete the course. The senior design class at BSC is the class that verifies that our students have demonstrated proficiency in the various areas. Prior to entering the senior design course, students must document their basic mechanical engineering technology skills by presenting a portfolio of work, and they also must pass a comprehensive test. After the students have been admitted to this course, they put together a proposal that details the work that will take place in the senior project; then they need to present their project and have their design project accepted by a review board that consists of their professor, sponsors from industry, and student representatives. Their industry-sponsored senior design project requires the students to participate on a team to design, build, test, report, and evaluate the results of the project. In this paper, the authors present the details of the process that takes place in order to ensure that our graduates have those skills.

Introduction

In recent years, the makeup and background of students in most engineering programs has changed dramatically. Programs are very diverse in both student motivation and background. In the 1960s and '70s the major deviation from the traditional undergraduate student was being a female in an engineering program. Recently, a more diverse student body exists; individuals from various races and countries, some with learning or physical disabilities, traditional students that work part time, nontraditional students (older individuals, supporting a family, working full time and going to school part time, etc.), single parents, students transferring from other institutions, students seeking a second degree, and the list goes on. In addition, the economic disparity between students is greater than at any other time in the past. While it is said that outside factors do not affect the grade that a student receives in a course, these factors may certainly affect the outcomes of some students. In some situations, a student does just enough work to get through a course and does not master the subject, or at least occasionally a course requirement may be softened because of some unusual circumstance. Employers require our graduates to be better prepared in more diverse areas. As a result, institutions must somehow ensure that their graduates are at least capable of several fundamental skills; therefore, it is necessary to implement and administer the rigorous requirements in the capstone senior design course in the Mechanical Engineering Technology Program at Buffalo State College. Additionally, it is important to effectively evaluate the performance of students in the senior design class.

College enrollment is growing and the make-up of a college classroom is changing with more students attending college in a nontraditional manner. The diversity of students in the MET program at BSC (see Table 1) is similar to many institutions. It is made up of males and females, African Americans, Hispanic Americans, Native Americans, Asian Americans, and foreigners. However, the typical individual enrolled in this program is Caucasian, employed (working full or part time in an industrial position), male, and is a resident in the geographic area. Many of the students are transfer students that may have a college degree. Almost any course on a student's transcript can be transferred from a previously attended institution. Students currently in the department have transferred as much as two years of college credit from more than fifty institutions. Since transfer credit is often given, there is often the question of how well the student was prepared at the college from which the course was transferred. While a student may have received credit for a course in thermodynamics or fluid mechanics taken at another institution, it is important to know what was covered and in what depth. Faced with this mix, the main concern is how to ensure that the students being sent into industry are truly prepared and ready to contribute.

When a degree is granted to a student, it is important that the student be familiar with several important principles from each course. A prerequisite test is given for each required mechanical engineering technology class taken at BSC. More importantly, the prerequisite test is important in

Table 1. Student Ethnicity Data at Buffalo State College

Native	Asian	Black/African American	Hispanic/ Latino	Multi-Race	Pacific Islander	White	Unknown
0.3%	2.5%	26.2%	11.9%	3.4%	0.2%	55.3%	0.2%

order to certify to potential employers that our graduates possess certain basic skills. Additionally, a comprehensive diagnostic test is taken by seniors before they are allowed to take the senior capstone course. Many institutions have a senior design course; each program has unique requirements. For many institutions, the course is mainly a design project that is completed by a senior during the last semester that the student attends school; few programs have an industrially based senior design project.

Flores et al. [1] described problems associated with the completion of senior design projects and their efforts to address those problems through the use of systems engineering techniques. This has led to more qualitative, competitive, and successful projects. Rahmat et al. [2] summarized the design of capstone project requirements in order to provide learning experiences to develop the students' ability to satisfy learning outcomes in their structural engineering program. Agboola et al. [3] described assessment methods for their capstone course. Parker et al. [4] discussed Alabama's program. At Alabama, students participate in a competitive design project in their first and second courses, where they focus on a single, external, industry-sponsored project. Bekkala et al. [5] described their senior design courses in electrical engineering. McDonald et al. [6] presented the details of using a multidisciplinary design team to work on senior design projects at Lake Superior State University. This is an excellent approach but the course is very difficult to coordinate.

The Accreditation Board for Engineering Technology (ABET) currently requires a capstone design component. The senior design course is probably the most critical course in the student's education. It requires a considerable time commitment by students, sponsors, and instructors. The course at BSC provides mechanical majors with an interdisciplinary creative design and problem-solving experience. The ability of students to effectively manage a project—and interact with team members on projects that stretch over several disciplines—are important lessons to learn early in a student's career. Exposure to these concepts will better prepare students for success early in their careers and help employed students to advance to new positions. Some students become very interested in the project and go well beyond the requirements of the project.

At BSC, the design team is responsible for the senior project from conception to completion. There are also additional requirements in the course to ensure a well-prepared graduate. The requirement most talked about by the students is the "diagnostic exam." In order to sit for the exam, students must first provide a detailed portfolio of their work that demonstrates their experience in the various required courses. When that requirement is satisfied, students are allowed to sit for the exam; this typically takes place the semester before the senior project is assigned. Exam content varies from year to year and includes multiple-choice and long-hand solution problems. The test is open book, with questions coming from various required courses in the curriculum. Students need to pass (> 60%) the diagnostic test before being allowed to register for the capstone course. If they do not pass the test, they must take the exam the following semester. The next major task is the design project, which takes place in local industry. Students need to report their progress weekly to the class. Additionally, there are several minor design projects (e.g., develop a web site to report the results of the project, create a larger team project that involves multiple groups, etc.). The culminating senior course changes slightly each year, but utilizes the same basic requirements.

Content of the senior design project includes engineering principles that are covered in the various core MET courses and include: design process, design teams, engineering management, engineering ethics, professionalism, project management, failure analysis, optimization in design, concept generation, financial considerations, concept evaluation, product design, product specification, product generation, product evaluation, proposal generation, final project assembly, and oral/written presentation. Design creativity is emphasized, with imagination and learning from mistakes being encouraged. The senior project requires a proposal, design, prototype, evaluation, and final report. This process is completed by a team of three or four students over one semester. Results are presented in a detailed final written report. There is a certain amount of group work involved in the senior design course; however, weak students cannot hide in their groups. All group members are required to be part of the group's oral and written presentations. Upon completing this course, students perform a self-evaluation of goals achieved and discuss the difficulties of attaining the goals that were set forth at the start of the project. Professors and sponsors evaluate all of the students on how well they achieved various skill areas. Additional student members evaluate other team members.

Evaluation—Diagnostic Exam

The comprehensive exam evaluates student knowledge of the required courses in the curriculum. Students may have taken these courses at BSC or another institution. The topics are fundamental in nature; however, because of the nature of the test and the breath of the subject areas, it makes for a very difficult evaluation. The students that do not pass the exam are not allowed to register for the senior design class and are required to take the course the next time it is offered. As one can imagine, this adds even more stress to the taking and evaluation of this course. The evaluation is a written test with several areas tested during the session. Question content comes from instructors that teach the courses at BSC, as well as old test questions from EIT review books. Graded tests are returned to the students for review (tests are kept on file by the instructor), and correct solutions are posted for limited viewing during class time. If they did not pass the test, the students must take another test during the following semester.

Senior Design Project

After passing the exam, students are allowed to register for the senior capstone course and may then start work on their senior design project. Initially, students will spend some time developing a proposal that outlines the work they hope to accomplish during the project. This proposal is presented to an evaluation board made up of the class professor, student members, and representatives from the sponsoring organizations. The students must also present their work to the board in order to ensure that proper procedures are being followed. Each board member evaluates the work and writes comments. Evaluations are given to the students after their presentations. If the board requires additional work, the group would have to resubmit its proposal before being allowed to proceed to the sponsor submittal stage. Students must answer to the board and, ultimately, to the sponsor.

This proposal is the agreement between the student group and the sponsor on what is required of the group, when the project will be delivered, and the various responsibilities on the project. A good deal of work is performed during the proposal stage; this virtually eliminates any problems in determining when the project is completed. Each group is required to make a short, weekly presentation to the board. The presentation is then evaluated using a rating system, with evaluation results being returned to the group. Mid-project and final reports, similar to the initial proposal, are also required. The final report is a summary of results and includes a recommendation for future work. Periodic videotaping of the oral presentations is made and the video used to help students to improve their presentation style. The final report is very easy to put together, since it is simply an assembly of all their previous work. Table 2 provides titles and some objectives of typical projects.

Summary

As one can imagine, this is not a course that the students initially think they would like. However, it certainly does evolve into the course that students have the most memories of; and, for many students, it ends up being their most meaningful course. The senior project is well received by all sponsoring industry members, not only because of the exceptional work that the students produce, but more importantly because it allows many of the companies to evaluate potential new employees. Many nontraditional graduates either change positions or receive promotions as a result of their projects. All in all, the course is a very demanding and a very satisfying course to teach. Some written comments from recent self-evaluations performed by graduates regarding the senior design course are included here.

- I think that this was the best class in the program.... The objectives of the course were clearly defined at the start and seemed very consistent with how our design project evolved. The class format emphasized the real world rather than a traditional class.... I think that the hands-on project was definitely an important exercise in preparing oneself for the real world of engineering.
- I felt the way that everyone in the class was forced to get up in front of the class every week and give a small presentation is one of the greatest things that this class can offer to an undergraduate student getting ready to go out into the work force.
- Truly this course has been the greatest challenge for me. To balance work, school, community commitments while at the same time forget the family and home responsibilities. I speak as a part time student with these sacrifices but would hate to experience this (senior design course) as a traditional student taking a full course load.
- Although challenging, time consuming, and all encompassing, this class was a great learning experience. The refresh of what was learned in previous years via the diagnostic exam is a great way to evaluate a student and a great way for a student to evaluate him/herself.
- ….I enjoyed my experiences in this class. From the diagnostic exam to the senior design project this class gave the chance to experience a large portion of what it is like to be an engineer.... I believe that the diagnostic exam was a very important part of this class. It forced me to review all the subjects that I have taken

Table 2. MET Capstone Projects at Buffalo State College

Sponsor	Project Title	Objective
Praxair	*Gas Manifold Component Redesign*	Redesigning three components of the gas generation system.
Cameron International	*Heat Exchanger Design*	Feasibility study on the development of an aftermarket heat exchanger.
RP Adams	*Steam Inlet Housing for External Backwash*	Design a system so that when a predetermined differential pressure is reached the unit goes into backwash mode and cleans each tube until the differential pressure is back down to normal operating pressure.
FS-Elliott Company	*Centrifugal Compressors: Inlet Throttle Valve*	Redesign compressor inlet throttling valve.
Fisher Price	*Dynamic Stability Testing for Children's Electric Powered Vehicles*	Design of test station to perform a dynamic stability test on a child's electric power vehicle.
FS-Elliott Company	*Hirth Attachment Coupling*	Use a Hirth Attachment Coupling to attach the main drive gear of an air compressor to the smaller pinion gear in order to power an air compressor.
Xylem Inc.	*Tapping Machine Redesign*	Objectives of this project were to create an easier, more efficient way to tap the aluminum carry and guide bar extrusions for Xylem's casketed plate and frame heat exchangers and make this process safe, fast, and less expensive.

and may have forgotten about...I don't believe that the exam was all that difficult, it was just a lot of material to cover.

- It (the senior design course) gives the student experience and confidence in the acquired education.

One comment from a first-generation college student that was important to receive went on to say, "I know it seems that I got off to a bad start.....This semester has been a great learning experience and it is very clear that this is the beginning of a much larger experience..." The same student, when discussing the evaluation of the final project by his peers, "... they even gave me a complement on the final product. That was a big reward. I had never received that before. Now that I know what it involves, I know more of what is expected and of what to expect. I am graduating this semester and I'm looking forward to a better life of hard work, accomplishments and respect."

As can be seen from these student comments, this course has offered a little something for everyone. Not every student liked every portion of the course; however, the course provides a challenging environment that, upon completion, produces a well-qualified student. BSC students are well received in industry, and sponsoring companies are eager to participate in the program.

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Biographies

MOHAN DEVGUN is currently a professor and department head for the Engineering Technology Department at the State University of New York College at Buffalo. Dr. Devgun may be reached at DEVGUNMS@BuffaloState.edu

DAVID J. KUKULKA is a professor at the State University of New York College at Buffalo and the coordinator of the Mechanical Engineering Technology Program. Dr Kukulka is a registered Professional Engineer in the State of New York and is a consultant for many local and national companies. Dr. Kukulka may be reached at kukulkdj@BuffaloState.edu

SOCIAL MEDIA AND ITS IMPACT ON THE QUALITY OF COMMUNICATION MANAGEMENT

Paul J. Thomas, Purdue University; Kevin C. Dittman, Purdue University

Abstract

Social media have become incredibly pervasive. Facebook, Twitter, YouTube, and a host of other social media applications are easily accessible from almost anywhere where there is Internet connectivity. Social media encompass not just social networking sites like these but also blogs, virtual game worlds, and collaborative projects. The Internet and social media have made the world more connected than ever before. But the result of this has often been a poor quality of communication between the users of these applications. In this paper, the authors examine the impact of social media on channels of communication and organizations and discuss the implications of social media on the quality of communication management in organizations, which covers the challenges and opportunities of effectively using social media.

Communication in Today's World

Oxford dictionaries define social networking as "the use of dedicated websites and applications to interact with other users, or to find people with similar interests to one's own." With the pervasiveness of the Internet and emergence of smartphones, the level of communication seen today in the use of texts, tweets, Facebook posts, Snapchat posts, etc. is increasing. With all of these social technologies so readily available, quantitatively we are more connected than ever before in history, while at the same time also potentially more disconnected than ever before. As human beings, our only real method of connection is through authentic communication. Studies show that only about 7% of communication is based on the use of verbal words, with the rest relying on nonverbal body language [1].

Even in the realm of corporations, the trend has been to use electronic communication using email or instant messengers like Lync instead of face-to-face or voice-to-voice communication [1]. According to Heller et al. [2], "companies have increasingly turned to virtual teams as a means of connecting and engaging geographically dispersed workers, lowering the costs associated with global collaboration, and enabling greater speed and adaptability." It is predicted that by 2020 over 50% of the workforce will be populated by millennials— those born between 1980 and 2000—who often prefer to use instant messaging or social media for communication, as opposed to talking to someone directly [1]. According to Langer [3], "social media has become a defining feature of modern culture and has become a central part of the way people communicate daily in both their social and professional relationships."

Kaplan and Haenlein [4] classified social media as follows: "social presence/media richness and self-presentation/self-disclosure yielding six different types of Social Media." Collaborative projects such as Wikipedia and blogs have the lowest scores, since they are usually text-based. Content communities like YouTube and social networking sites like Facebook give users the option of sharing pictures, videos, and other media in addition to text-based content. Games such as World of Warcraft hold the highest scores, since they attempt to replicate face-to-face interaction in a virtual world [5]. According to a study by Kirakosyan and Dănăiaţă [5], "Self-presentation refers to how in any social interaction people have the desire to control the impressions other people form of them and self-disclosure is a critical step in the development of close relationships." With the growing prevalence of social media, organizational communication management strategies should integrate the use of blogs, social networking sites, and content communities to maximize their reach to different audiences.

Organizational Impact of Social Media

As of 2009, "Facebook had more than 175 million active users. At the same time, every minute, 10 hours of content were uploaded to YouTube and the image hosting site Flickr provided access to over 3 billion photographs" [4]. But such pervasiveness also comes at a cost to corporations, because they trade ubiquity for losing control over the information about them on the Internet. Today, an Internet user doing a Google search of any top brand will not only see the corporate webpage and the corresponding Wikipedia entry, though Wikipedia explicitly forbids participation of organizations and brands [4]. This results in users being able to post truthful yet negative information about corporations and their missteps. Historically, companies leveraged press announcements and public relations managers to control the information available about them. Kaplan and Haenlein [4] also noted, "Today, however, firms have been increasingly relegated to the sidelines as mere observers, having neither the knowledge nor the chance and in some cases even the right—as with Wikipedia; to alter publicly posted comments provided by their customers."

Users are also free to air grievances on social media applications like Facebook, Twitter, etc. and post negative reviews about products or services on websites like Amazon and Zomato. To maintain the integrity of the organization, the responses to such events must be strategic. Most organizations have systems in place to deal with these kinds of scenarios [6]. A common sight in Amazon and Newegg reviews is a customer service representative responding to a customer who posted a negative review. In social media services, users tend to generate unverified information—both true and false—and put forth ideas about organizations that can differ substantially from what they share with the public [6].

Social Media and Communication Management

Welch and Jackson [7] stated, "Communications management is the systematic planning, implementation, monitoring, and revision of all the channels of communication within an organization, and between an organization and other organizations or customers." Organizational communication looks at communication and organizational behavior and is concerned with the symbolic use of language, how organizations function, and what their goals are. The discipline of organizational communication focuses organizations and their communication processes, which are used to both "describe and explain an organization" and an approach to "communication as a phenomenon" in organizations [7]. According to Koontz and Weihrich [8], the guidelines for effective communication are as follows:

1. Senders of the message must be clear as to what they want to communicate.
2. Planning of the communication should not be done in a vacuum. Other people should be consulted and encouraged to participate.
3. The function of communication is more than transmitting information. It deals with emotions that are important in interpersonal relationships between superiors, colleagues, and subordinates in an organization.
4. Effective communication is also a responsibility of the receiver.

   Social media have had a tremendous impact on the quality of communication. According to Marom [9], most business communication now occurs via e-mails, texts, and other technology-enabled media. The common aspect for all of these means of communication is that none conveys body language, making the potential for misinterpretation massive. Employees, amidst their rush and stress, often do not take the time to consider the nuances of their writing. Conflicts may arise over the tone of an e-mail or the recipients marked in the cc: list [1]. Conveying emotions is the Achilles heel of communication across social media.

When using instant messaging services, does the use of all capital letters indicate that the person is yelling? Are one - and two-word responses an indication of the person's reluctance to communicate with you? Does a smiley face convey agreement? Social media introduce a significant degree of ambiguity to communication, and false conclusions may be drawn from these [1]. Factoring in these points, one can conclude that social media is a very weak form of communication [8]. Weak communication is often a result of lack of planning, unclarified assumptions, semantic distortion, poorly expressed messages, communication barriers in international environments, poor listening, premature evaluation, impersonal communication, distrust, fear, insufficient period for adjustment to change, and information overload [1]. Social media leave significant room for all of these factors to interfere with effective communication [13].

Opportunities of Social Media

Fischer and Reuber [10] stated, "Social media has become an essential part of integrated organizational communication strategies, mainly due to its inexpensive and intuitive means of sharing user-generated material." The dynamic nature of social media allows adjustments to be made according to the needs of the consumer [11]. Sashi [11] established that more relational exchanges over social media can lead to the formation of emotional bonds which in turn causes customers to become advocates for brands and products. Social media marketing, unlike traditional marketing techniques, makes use of information exchange between customers to the end of increasing both customer satisfaction and advocacy [11]. The best examples of this are customer reviews and other content like pictures and videos shared online about various products and services. The prevalence of social media has given consumers the impression that they are active participants in the organization. Langer [3] had the following advice for organizations, "To be successful in their social media strategies, organizations need to remember that consumers are in control of their online experiences. Organizations must give consumers a valid reason to engage electronically by providing them with a unique and customizable experience." To this end, organizations must recognize what motivates customers to use social media and their social media marketing strategy should aim to bring consumer experiences to the front [3].

Social media afford organizations an opportunity to build brand awareness. Organizations should make a concerted effort to adopt social media not only as a means to improve their reputations but to build deeper connections with the consumers [3]. The American Red Cross uses Twitter and Facebook to identify what areas of the organization require improvement [12]. Briones et al. [12] stated, "The aim being the use of social media to develop and build relationships with a variety of audiences including volunteers, media, students and communities, with some of whom they already have established relationships." Many organizations run competitions on YouTube, Facebook, Flickr, etc. as a means to drum up interest in one of their products or services. Kirakosyan and Dănăiaţă [5] gave the following example: "In 2007, Procter & Gamble organized a contest for its over-the-counter drug Pepto-Bismol, whereby users were encouraged to upload to YouTube 1-minute videos of them singing about the ailments Pepto-Bismol counteracts, including heartburn and nausea."

Social media tools, by directly delivering information about improvements to participants, can make the process of process management more efficient. Pearson [13] gave the following example: "If there is a quality issue in goods received, immediate online communication between customer and supplier in response to a blog or other online post can enable a discussion about how best to address the problem and improve the process." According to Kleim [14], "Social media can also be an excellent tool for bridging the gap between external networking and internal integration." Social media adoption in organizations can lead to tighter feedback loops if, for example, the IT department uses social media to communicate feedback about new products to the engineering department [13].

Implications of Social Media

The increasing prevalence of social media has led to the tendency of personal social accounts to be used for professional reasons. This is usually done by advocating for their respective organizations using their personal social media accounts [15]. For example, employees of certain games companies put teasers and other related content of upcoming games on their personal Twitter accounts as means of promotion along with the purpose of gathering responses and feedback. Social media also serve to connect professionals with one another. The prime example of this is LinkedIn, which is the professional social network. LinkedIn currently has over 433 million users, who use the service to connect with other professionals [16]. The purpose of these interactions and connections could be to share knowledge, pitch business prospects, or create partnerships. In Langer's [3] study, participants utilized social media to gather a more rounded perspective of their co-workers, which enabled them to establish a good rapport.

Challenges of Social Media

Waters and Williams [17] stated, "Despite evidence suggesting that organizations need to adapt better to this new system of communication, research shows that most organizations are still engaging in one-way communication, and responding minimally to consumers through social media." Organizations cannot control what people may post on social media platforms. Langer [3] concluded, "To maintain as much regulation as possible, it is imperative that organizations consistently participate in these ongoing interactions so that they may avoid both internal and external negative consequences." The greatest challenge faced by organizations in utilizing social media is finding an effective strategy to maintain it. The paradigm shift from being reactive to needing to be proactive is something many organizations have struggled to come to terms with [3]. Social media also have a notoriously low engagement rate, because users are bombarded with a clutter of information from different media [9]. So an organization has to be careful in selecting multiple social media outlets and not managing any of them correctly or effectively [19]. Facebook "likes" do not equate to users who are actually engaged with an organization's content. Frequent comments, retweets, and being tagged in comments are some of the indicators of real engagement [3].

Although social media serve as a platform for sharing ideas and knowledge [3], obtaining knowledge via social media has its pitfalls. The information shared can be misleading or controversial, because the sources are rarely cited and often opinions can be put forward as facts [20]. Social media have also given people the power to voice their opinions on companies effortlessly, and it does not take much for an innocuous tweet or Facebook post to snowball and go viral. Users expect immediate gratification, and organizations have to be on their toes to quell any fires before they get out of control [3]. Also, introducing social media into a highly regulated industry such as banking has proven difficult, due to security, compliance, and risks [5].

Recommendations for the Effective Use of Social Media

The College of New Jersey [21] states, "Every organization should have a clear and well-defined social media policy which should cover what employees are allowed to post on social media which may or may not be related to the organization." Any content posted—text, photos, audio, or video—must be in line with overall communication strategy and must bring value to the discussion. When posting content, the audience must be engaged directly either by asking questions or soliciting feedback. The 80/20 rule helps greatly in achieving this: show the audience what they want to see 80% of the time, and 20% of the time show them what you want them to see [21].

Managers must advise employees to double-check any communication before it is sent out and must encourage direct communication either through phone calls or face-to-face conversations to resolve any ambiguous communication [14]. Communication is always two-way, so it is also the responsibility of the sender to ensure that the message was understood as received [8]. When dealing with teams composed of people from different generations or with virtual teams spread out across the globe, it is important to understand what the preferred mode of communication is for the individual: baby boomers tend to prefer direct face-to-face communication or phone calls, while millennials tend to prefer electronic communication [1]. Cultural boundaries also need to be respected: an accepted tone for electronic communication in one country could be deemed as rude in another [8].

Conclusions

As social media become ever more mainstream, they leave a significant impact on how individuals and organizations communicate. Social media can be a very effective tool in building and sustaining relationships with customers or a fan-base. Social media allow organizations to engage with consumers directly in an inexpensive and efficient manner, when compared to traditional communication tools. Therefore, it is essential for organizations of any size to embrace social media as an integral part of their communication management strategy. Historically, companies leveraged press announcements and public relations managers to control the information available about them [3]. The rapid adoption of social media has resulted in a paradigm shift where customers hold just as much, if not more, power than the corporations about their perceived brand image. Consequently, communication management strategies have had to incorporate steps to quickly deal with negative customer reactions on social media before they evolve into a full-blown public relations nightmare.

Social media is not a panacea for the absence of a comprehensive communication strategy, and the media themselves are not without fault. Social media strip away emotion and body language from communication, resulting in the introduction of ambiguity into communication. This ambiguity can lead to misinterpretation of messages, which, in turn, causes conflicts or errors. Managers must be willing to tailor communication channels based on the composition of their teams and, if geographically dispersed virtual teams are involved, managers may be privy to the different kinds of communication etiquette that is expected by different cultures. Despite the pervasiveness of social media, it is still as important as ever to connect with people as human beings and engage with them in direct communication that conveys emotion and body language, because it is still the most effective form of communication. The research area of quantifying the monetary impact of social media adoption on an organization is still in its infancy and further studies would be valuable.

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Biographies

PAUL J. THOMAS is a graduate student at Purdue University working under the mentorship of Professor Kevin C. Dittman. His graduate study focus is IT project and quality management. Mr. Thomas may be reached at pjosekut@purdue.edu

KEVIN C. DITTMAN is an associate professor of computer information systems and technology at Purdue University. Professor Dittman specializes in information systems business analysis, requirements engineering, quality management, and project management. He has co-authored leading textbooks on systems analysis and design and project management. He has also published several other scholarly papers and journal articles. Professor Dittman has over 31 years' of industrial and consulting experience in the information technology arena with top corporations such as Cook Medical Corporation, Lockheed Martin, Caterpillar, and Cummins Engine. Professor Dittman may be reached at kcdittman@purdue.edu

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Editor-in-Chief
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College of Engineering and Computer Science
Room: JD 4510
Northridge, CA 91330
Office: (818) 677-5003
Email: mrajai@csun.edu

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Philip D. Weinsier, Ed.D.
Editor-in-Chief
Phone: (419) 433-5560
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