# ASEE 2015

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# Planning for a Health Care Technology Certificate

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**M. Kudret Yurtseven**
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## Abstract

Herein will be described the planning to reactivate a Health Care Technology Certificate in the Department of Engineering Technology and Industrial Distribution in the College of Engineering at Texas A&M University – College Station. The certificate was started in FY 2010-2011. The plan is to broaden it to include both strong healthcare distribution and engineering technology components. For the certificate, a consistent list of course offerings and more involved undergraduate participation is needed. Thus far three semesters of a healthcare distribution course with an average enrollment of 50 students have been held. As a result of the recent loss of the faculty member teaching this course and spearheading this certificate program, there was no one left to teach this course. The author prepared to do so while giving it a stronger technical component. There was also no one left to teach the health care technologies course because of another faculty departure.

## Keywords

Healthcare technology, healthcare distribution, healthcare certificate, industry-related courses, student interaction pedagogy

## Introduction

The author has now taught the healthcare technologies course once, having already taught a similar course when he was in the Purdue system. The plan is to include collaboration with and mentoring the other professor in the department who teaches the medical manufacturing course for the certificate. The last course in the certificate is a medical terminology course for healthcare professionals. It is taught outside the Department of Engineering Technology and Industrial Distribution and always has a good enrollment. The plan is providing an opportunity for the author to not only develop and teach in this certificate program, but also to become the course coordinator for the healthcare certificate with the end goal being to get it approved. There is a need for such a certificate due to the aging of our population in the United States.

## Certificate Program in Healthcare

According to the Bureau of Labor Statistics, Healthcare was the largest industry in 2006, providing about 14 million jobs.[1] With the baby boomers retiring now, the emphasis on Healthcare is becoming stronger. More people are in need of the right drugs/equipment at the right time, right quality, right quantity, and right price.

Additionally, with the U.S. Food and Drug Association, the U.S. Drug Enforcement Administration and other government agencies requiring strict distribution policies against counterfeit drugs and secure supply chains, the focus of healthcare distribution supply chain is changing. This requires people with a non-traditional set of skills in distribution to manage their supply chains.

Traditionally, this industry recruits college graduates either from a logistics department (with limited product and distribution processes knowledge) or from a biomedical department (with limited logistics knowledge). A Certificate in Healthcare Technology will provide students with specific product and process knowledge equipping them with the distribution skills to manage these supply chains.

The proposed undergraduate certificate in Healthcare Technology will consist of four, three credit hour courses for a total of 12 credit hours. Core courses will include IDIS 489 (Distributor Operations in Healthcare) and a capstone course in Healthcare Technology, in which the student will work on an industry project with leading companies in the Healthcare industry. The third course will be a survey course in healthcare technologies from the Electronics Engineering Technology program (ENTC 489) within the Engineering Technology and Industrial Distribution (ETID) Department. The final course will be a Healthcare quality processes elective from the Mechanical and Manufacturing Engineering Technology (MMET) program in the ETID Department. This certificate program will graduate students with a strong foundation in healthcare Technology, with product, sales and distribution knowledge.

## Funding and Development

The funds requested for this Certificate will be used in developing course materials and establishing relationships with companies willing to support the program with projects, funding, and recruitment opportunities. This planned development for the near term and long term success of the program and its students will create an environment of mutual benefit for the partnering companies, Texas A&M University, and its support organization such as the Texas Engineering Experiment Station (TEES) and the Association of Former Students.

To the best of our knowledge, Texas A&M University has no established relationship with companies in the Healthcare Technology industry. Distribution is one of the largest segments of the healthcare industry and is growing rapidly. Texas A&M's Industrial Distribution Program is world renowned as the top distribution program in the world. Given the ongoing work in healthcare by other divisions at Texas A&M University and Houston's ascendancy as one of the leading Biotech cities, establishing the first Healthcare Technology Certificate at the Texas A&M is a logical next step.

The faculty has identified five distribution channels: (1) Pharmaceuticals (already well penetrated by the Industrial Distribution Program); (2) Hospital Maintenance-Repair-Operations (a core competency of the Industrial Distribution Program not yet established with Healthcare companies); (3), (4) Prosthetics, Medical Equipment Distribution, and (5) Home Healthcare Services (possibly the largest area). Each channel is either underserved by Universities or not served at all. Presently, Texas A&M's Industrial Distribution Program has developed significant relationships within the Healthcare Technology Industry that includes the Healthcare Industry

Distribution Association (HIDA) and McKesson (the largest Healthcare distributor in the world, sales greater than $100 billion).[2]

During the development phase, we will provide the Association, the Dean's office in the Look College of Engineering, the Texas Engineering Experimental Station (TEES), and other relevant parties with quarterly updates on companies and trade association partnerships. After launching the Certificate, our report will also include course development updates, research initiatives, and regular updates on the number of students graduating through this certificate program and the companies that are hiring them.

## References

1 Center for Health Workforce Studies, "Health Care Employment Projections: An Analysis of Bureau of Labor Statistics Occupational Projections 2010-2020, March 2012, pg. 4.

2 Lakraj, Vishnu, "McKesson is one of the Most Powerful Players in the Pharmaceutical Supply Chain," McKesson Corp Analyst Report, February 2015, pg. 2.

## Walter Buchanan

Walter Buchanan is the past J.R. Thompson Chair Professor at Texas A&M University. He is a Fellow and served on the Board of Directors of both ASEE and NSPE, is a Senior Member of both IEEE and SME, is a Past President of ASEE, Past-Chair of the Professional Engineers in Higher Education of NSPE, is a Past President of the Massachusetts Society of Professional Engineers, and is a registered P.E. in six states. He is a past member of the Executive Committee of TAC of ABET. He is on the editorial board of the Journal of Engineering Technology and the American Journal of Engineering Education, among others. He has authored over 200 peer reviewed publications and has been a principal investigator for the National Science Foundation.

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Ali Mehrabian, Ph.D., is currently a faculty member at Daytona State College. He is a member grade of American Society of Civil Engineers (ASCE) since 1993. His scholarly activities encompass more than 60 peer-reviewed publications. He has served as both PI, project manager and co-PI for the grants funded by National Science Foundation and other funding agencies. His research interests also include technical and pedagogical aspects of engineering and technology.

## Alireza Rahrooh

Alireza Rahrooh received his B.S., M.S., and Ph.D. in EE from the University of Akron.. He worked as an Electronic Engineer from 1979 to 1984. He was involved in conducting research for the Electrical Power Institute and NASA Lewis Research Center from 1984 to1998. He was appointed to a faculty position in EE at Penn State University in 1988. In 1994, he joined ET at UCF until August of 2010 when he moved to Daytona State College. He has presented numerous papers at various conferences, is the author of more than 100 technical articles and recipient of 30 awards. His research interests include simulation, nonlinear dynamics, system identification and adaptive control. He is a member of ASEE, IEEE, Eta Kappa Nu, and Tau Beta Pi.

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# Redesigning the Student Learning Approach through Personality Types and Pedagogies in an Undergraduate Engineering Course

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## Abstract

As the National Science Foundation and engineers throughout the world seek to strengthen the future of the engineering profession, the Civil Engineering (CE) program at the United States Coast Guard Academy embodies this initiative with a student focused approach. One course in particular, Materials for Civil and Construction Engineers (CE Materials), was restructured focusing on multiple pedagogies (e.g. traditional chalkboard writing, presentations, field trips, labs, etc.) to appeal to different student learning preferences and create a more inclusive learning environment. Utilizing the Myers-Briggs Type Indicator, instructors focused on the first two dichotomies, Extroversion vs. Introversion and Sensing vs. Intuition. With an innovative approach towards CE Materials, the goal of stimulating independent thinkers and assisting students with the retention of core course material is being achieved across a range of student learning preferences. By teaching the course in a way that encompasses all learning preferences, a greater breadth of students can succeed in and enjoy a civil engineering curriculum.

## Introduction

Typical civil engineering courses rely heavily on quantifiable material, design work and calculation. As a result, the classic engineering curriculum generally attracts students who prefer numbers and a reference based learning style. Therefore, when a course varies from this style and relies more heavily on memorization than the use of a calculator, the typical engineering student is less stimulated by the material and perceives the course as “soft”. At the United States Coast Guard Academy (USCGA), Materials for Civil and Construction Engineers (CE Materials) – a required course in the CE curriculum – is one such course. CE Materials introduces students to the construction subfield and is essential to student understanding of materials utilized in the CE profession. Over the course of the semester, students are familiarized with civil engineering construction materials such as aggregates, concrete, asphalt concrete, steel, wood, and geosynthetic materials. CE Materials has some design work and calculations typical of an engineering course but relies heavily on memorization of basic material properties. Due to the lack of” hard engineering” (i.e. calculations and lengthy designs), CE Materials is not viewed as a “typical” CE undergraduate engineering course and has historically been viewed by students as “weak” and “boring.” These perceptions have become a source of innovation within the program as faculty seek new and exciting methods to teach and inspire CE students in all required courses.

## USCGA Civil Engineering Program

As the nation’s smallest service academy, the USCGA’s student body, of approximately 1000 cadets, is tasked with the dual mission of earning a Bachelor’s of Science Degree and training service ready Ensigns to commission in the United States Coast Guard. Due to this two-pronged mission, cadets in the Civil Engineering program face challenging time constraints as they are required to complete an Accreditation Board for Engineering and Technology (ABET) accredited CE curriculum in addition to military requirements. The demanding schedule results in just one free elective over the four year course of study. Graduates of the USCGA CE program have the opportunity to pursue a variety of career paths within the U.S. Coast Guard (engineering and non-engineering), therefore the CE program educational objectives (PEOs) are purposely broad and aim to meet the needs of the U.S. Coast Guard in and out of the field of Civil Engineering. The CE PEOs are to produce graduates who[1]:

1) Are prepared for professional practice in engineering positions as U.S. Coast Guard Junior Officers
2) Are prepared for a variety of U.S. Coast Guard career paths, based on their abilities to apply fundamental engineering principles in dynamic technological environments.
3) Have the ability and desire to continue to grow intellectually and professionally.
4) Are prepared to provide appropriate civil engineering expertise to the U.S. Coast Guard.

As the primary accession point for Civil Engineers into the U.S. Coast Guard, the quality and quantity of USCGA CE graduates directly affects the Civil Engineering community within the U.S. Coast Guard. The ability of our graduates to attain professional licensure as well as professional practice in alternate Coast Guard career paths is of the utmost importance.

## Materials for Civil and Construction Engineers

The Materials for Civil and Construction Engineers (CE Materials) is a 4 credit course offered at USCGA and a requirement for students obtaining a Civil Engineering Degree. As an introductory course to the construction subfield, CE Materials teaches students to identify and analyze relevant civil engineering materials as well as construction equipment and techniques. The emphasis of the course is placed on understanding the engineering properties of these materials, selection of materials and practical construction methods and performance. There is a design component to the course which includes the designing and testing both a Portland cement concrete (PCC) mix and hot mixed asphalt (HMA) concrete. While there are some design elements of the course, the focus of the course is on student obtainment of a broad spectrum of material knowledge – relying more heavily on memorization skills than design calculations. Upon course completion, students should have a basic understanding of the material and engineering properties associated with civil engineering materials and should be able to articulate how these properties affect selection in construction and in service performance.

## MBTI Methodology

The goal of redesigning CE Materials was to stimulate independent thinkers and assist students with the retention of core course material across a range of student learning preferences by designing new and innovative lesson plans. These lesson plans aim at presenting the material in a way that all learning types are reached so that overall a greater breadth of students will succeed. In order to determine the best methods to accomplish this objective, the Myers-Briggs Type Indicator (MBTI) was first utilized. “The essence of the MBTI theory is that much seemingly random variation in behavior is actually quite orderly and consistent, being due to basic differences in the way an individual prefers to use their perception and judgment."[2] By identifying the orderly and consistent behaviors and categorizing those behaviors based on Carl Jung's study on extroversion and introversion, it was further expanded upon and "subdivided into eights types by identifying two pairs of opposite mental functions: two opposite perceiving functions and two opposite judging functions."[2] Isabel Myers and Katherine Briggs then interpreted Jung's theory in the MBTI personal type inventory, which is widely used today to give individuals a better understanding of their personality preferences and how they impact their interactions with others. Framing the course based on this theory gave the best opportunity to achieve the end goal of being able to excite and reach the entire audience across individual learning preferences.

Employing MBTI as a learning model, instructors focused specifically on the first two dichotomies, Extroversion vs. Introversion (E-I), and Sensing vs. Intuition (S-N). First, the E-I dichotomy focuses on where people direct and get their energy from. More specifically students who have a preference towards E get and focus their energy on the outside world, while students who have a preference towards I focus their energy on the inside world[2]. Determining how and where students get their energy from is integral to the first aspect of the goal - exciting students on the subject. Secondly, the S-N dichotomy focuses on how people perceive or take in information. Understanding how students take in the information is essential towards achieving the second aspect of the goal - reaching the entire audience. More specifically students with a preference towards S like information that is to the point and matter of fact, while students with a preference towards N like information that is focused on the bigger picture.[2]

## Current CE Materials Course Assessment

To redesign the course, the baseline curriculum was dissected and lesson delivery methods were categorized based on tacit (experiential) or explicit (articulated) knowledge. Once all the activities were defined, an evaluation of the current course schedule revealed that 23 out of the 29 classroom instruction, not including laboratory, were primarily delivered by the instructor and focused on explicit knowledge (Table 1). This analysis indicated an absence of tacit knowledge in the course, indicating a potential area for improvement. Five years ago, when one faculty member retired, the course underwent its first iteration of change. Prior to this change, tacit instruction existed solely during the designated laboratory periods. In 2010, limited tacit instruction was introduced into the classroom portion of the course with success. With minimal changes implemented in course since 2010, the first step in this current assessment was to link the existing classroom delivery methods to the explicit or tacit dichotomies (Table 1) thereby identifying potential areas for improvement.

**Table 1: Course Evaluation Matrix**

| Classroom Activities | Delivery Method | Dichotomies Link |
|---|---|---|
| *Previous Course* | | |
| Exams | Explicit | I, S/N |
| Fill in the blank outline | Explicit | I, S/N |
| Homework - short answer | Explicit | I, S |
| In class demonstrations (physical) | Tacit | E,S/N |
| Laboratory | Tacit | E,S |
| Laboratory Reports | Explicit | I,S |
| Videos | Explicit | I, S/N |
| Writing lesson on the board | Explicit | I, S |
| *Additions from Current Course* | | |
| Student Presentations | Both | E,S/N |
| Assigned Readings | Explicit | I,N |
| Field Trips | Tacit | E, N |
| Green Materials (ID) | Tacit | I, N |
| Homework - design problems | Explicit | I,N |
| Pavement Mapping | Tacit | I, N |
| PowerPoint lessons | Explicit | I, S |

While all students have their individual MBTI preferences, the goal is not to tailor the course to the specific preferences of any one student, but to ensure that course pedagogy is diverse and fully inclusive of all learning styles. By linking the assessed dichotomies to each classroom session, it was clear that the course delivery methods being utilized were not well representative of a variety of different learning preferences. Through the process of solely evaluating the classroom instruction, not including the laboratory periods, it was clear that the primary classroom delivery method was explicit (Figure 1). In the pre-2010 CE Materials course, the majority of the coursework catered to students who prefer the I and S dichotomies – those who prefer to learn via explicit or articulated knowledge. After the first iteration of changes to the post-2010 course, there continued to be a clear lack of coursework designed for the E and N learning preferences – those students who prefer to learn via tacit or experiential knowledge (Figure 2). Reflecting on the original goal of this assessment, creating an exciting and inclusive classroom experience, there continued to be a need to alter course pedagogy from the dominant learning style to create a classroom experience that would appeal to a more diverse student population. By framing the course such that all student learning preferences are fully represented, a more inclusive learning environment is fostered resulting in a broader population of students being educated and inspired as they progress through this foundational course.

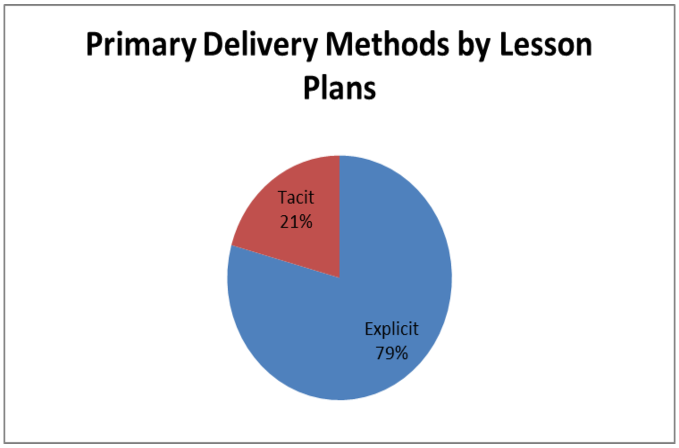


**Figure 1: Primary Delivery Lesson in Current Course**

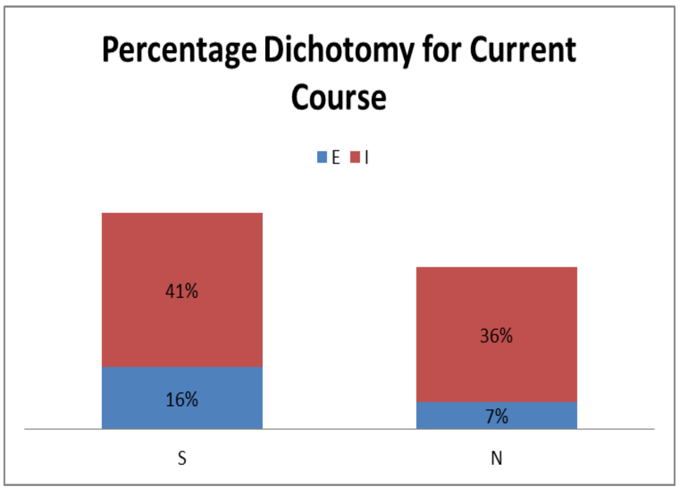


**Figure 2: Dichotomy Percentage in Current Course**

## CE Materials Current Course Adoptions

After the first iteration of significant course changes in CE Materials, more tacit instruction methods were incorporated with the goal of appealing to learners who prefer the E and N dichotomies. As stated, initially tacit instruction was solely utilized in CE Materials during the laboratory periods. Therefore, labs appealed to the students presenting the I and S dichotomies and the classroom portion of the course appealed to students preferring the E and N dichotomies. Many students found this disconnect frustrating. After the first iteration of change to this course, the following course modifications were made:

1) Student 5 Minute Presentations
2) Sustainable Material Identification
3) Hot Mixed Asphalt (HMA) Pavement Mapping

*Student 5 Minute Presentations*

Short student lead presentations were incorporated into the course and became part of the student's overall course grade. For the 5 minute presentation, the student was charged with identifying and researching a contemporary civil engineering method or material and presenting that method or material to the class. Each student is required to give one presentation and the presentations are scattered throughout the semester.

This small, yet effective assignment, has added tremendous benefit to the course and student learning process. First, the assignment appeals to the E dichotomy but has both a tacit and explicit component. The student completing the research and the presentation has a tacit experience while their classmates, listening to the presentation, have an explicit experience. Because the assignment charges the students with finding a novel topic, new materials and methods are introduced into the classroom. Additionally, the students take ownership of these new topics because they are selecting topics of interest to them. The assignment is intentionally vague, giving the students the freedom to not only pick a topic but also present the material in either a S or N fashion. This freedom stimulates the interactive thinking process that appeals to a variety of learning preferences and also makes the presentation memorable for not just the presenters, but also their peers.

*Sustainable Material Identification*

The emerging field of sustainable materials is vast and comprehensive. This topic can easily fill several 75-minute class periods or could be truncated to one quick PowerPoint presentation, an explicit delivery method. However, in an effort to avoid overwhelming the students with the broad spectrum of sustainable materials and maximize their retention of the material, the instructors created a "green material scavenger hunt." Each student is tasked with researching a different, niche sustainable topic at the beginning of the class period. After a short period of time the students are then asked to informally present the material to their classmates; both the research and the presentation happened during the same class period.

Unlike the 5 minute presentations, the student does not have the freedom to choose their own topic, however, similar to the presentations he/she does have the freedom to present the material in whichever manner he/she chooses. The students are given a specific topic, (i.e. green roofs) but they are given no guidance on what to present about the topic. This vagueness, again, provides the student the opportunity to discuss the material in terms of bigger picture or matter of fact. This tacit delivery method increases the student's comprehension because he/she is forced to learn the material well enough to briefly present it. In addition to improved knowledge retention, both the green material scavenger hunt and the 5 minute presentations, provide the students an opportunity to speak in front of their peers and become more comfortable presenting material.

*HMA Pavement Mapping*

Distress pavement mapping was also successfully introduced into the course as an alternative to a standard classroom meeting. In class prior to the pavement mapping exercise, a PowerPoint presentation, coupled with chalkboard notes, identifies for students the various degrees of asphalt pavement failure, i.e. longitudinal cracking, potholes, etc. During the following class period, the students go outside where they are tasked with mapping a certain portion of distressed pavement on campus. The students are placed into groups and given separate sections of the pavement to map. Positive feedback from the students, both verbally and during assessment, reaffirms that this tacit classroom activity improves the overall student retention of distress identification. Coupling the initial explicit learning environment with the tacit pavement mapping activity reaches a broader range of student learning types and ensures that all students are exposed to this element of the course in a method that is most meaningful to them.

## Future Course Proposed Changes

Even with current course alterations, the percentage of primary classroom deliver methods clearly favors the explicit learner. To appeal to both dichotomies more equally, this course could benefit from additional tacit instruction. In an effort to add more tacit instruction to the curriculum, two additional changes are planned for incorporation in the coming semester:

1) Student in class research and presentation
2) Guest Speakers

*Student in-class Research and Presentation*

Several topics were identified as potential areas for students to informally present the material to their classmates, similar to the green material scavenger hunt previously adopted into the course. The instructors noted that the course can take advantage of the introductory topics which are generally not complex, but require only the presenting of basic facts, such as the material's properties. The general outline for this type of class would be first the instructors would divide the class material into different samples. Ideally, the instructor will have actual materials for this purpose, to help the students identify the physical material. After forming groups, the students would first pick a sample, at random. The students will then spend the next 20-minutes, of the 75-minute period, researching their sample. The instructors would provide a handout with questions that the students would be required to answer. They would be allowed to use their textbooks, the library website and other reference material to answer the questions. The remainder of the class would be spent with the students presenting the material to their classmates. From the beginning of the class period, it would be made evident that the students are responsible for learning all the material, and the instructors would not be reiterating the topics.

The benefit of this type of instruction is two-fold. First, having the students identify samples and research different topics would make the lecture more interactive, and therefore create a tacit learning experience. Next, group work appeals to the extroverted student, however listening to the presentations and taking notes appeals to the introverted student. Both the S and N dichotomies are also met with this type of lesson plan. After meeting the basic requirements, the students will have the freedom to focus on whichever aspect of the material is most interesting to them. Depending on their preference this could be a bigger picture presentation (N) or a more matter of fact presentation (S).

The three course topics that have been identified as plausible for this type of classroom lecture are geosynthetics, engineered wood products and the mechanical properties of corrosion. These topics were identified because they can be presented broadly, can be simplified when providing an overview and the instructors can realistically provide physical samples to the students to use/analyze.

*Guest speakers*

Inviting guest speakers into the classroom can be categorized as either a tacit or explicit. If a guest speaker discusses the material simply in a way that the instructor might present the material, i.e. a PowerPoint presentation, then the lecture is an explicit one. However, if the guest speakers have a more interactive lesson then the presentation becomes tacit. To ensure guest speakers are the latter, specific lessons are considered. To ensure a tacit guest speaker, the course instructors will only use guest speakers that would be able to give a more interactive lesson, based on the nature of their expertise and personality.

Two topics that were considered for interactive guest speakers were the pavement construction of Portland cement concrete and hot mixed asphalt. Ideally, the instructors will be able to reach out to construction managers of local ongoing pavement projects. The intention would be for the students to be able to walk a construction site while the guest speaker was explaining the intricacies of placing pavement. The class may have to start out with a brief lecture, in the classroom, explaining the overall process and major construction equipment. Then, the students can walk onsite while the speaker enforces the lesson.

This instruction would be a primarily tacit instruction due to the interactive nature of walking into a construction site. The lesson could appeal to the E and I as well as the S and N dichotomies. The main challenge posed with this type of instruction is finding a local construction project the students could visit within the allotted classroom time as well as the appropriate guest speaker.

## Evaluation of Proposed Course Alterations

The overall proposed changes of the course would add additional tacit delivery methods to the course. Altering 5 classroom lectures would result in 62% explicit instruction and 38% tacit instruction (Figure 3). However, if the laboratory sessions are included in the tacit vs. explicit count, the delivery method break down swings to more tacit than explicit instruction (Figure 4). For a course that has historically been viewed as “boring” by the students, due to the focus on memorization, a slightly more tacit approach is sought. In addition, the implementation of the new material dramatically increases the percentage of lessons that will appeal to students who prefer the E dichotomy in this course. Depending on the student learning preference and the manner in which they present materials assigned to them, these additions could potentially increase the N dichotomy of the course as well. Changes presented in this paper are aiding the CE Materials instructors in achieving their objective of reaching different learning preferences (Figure 5).

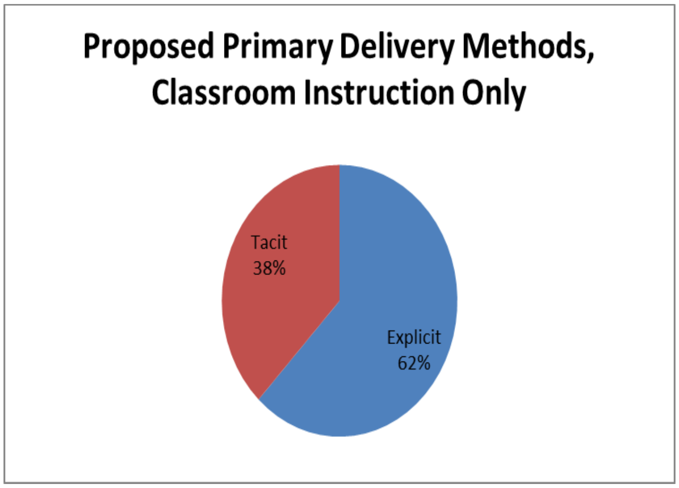


**Figure 3: Proposed Primary Delivery Methods**

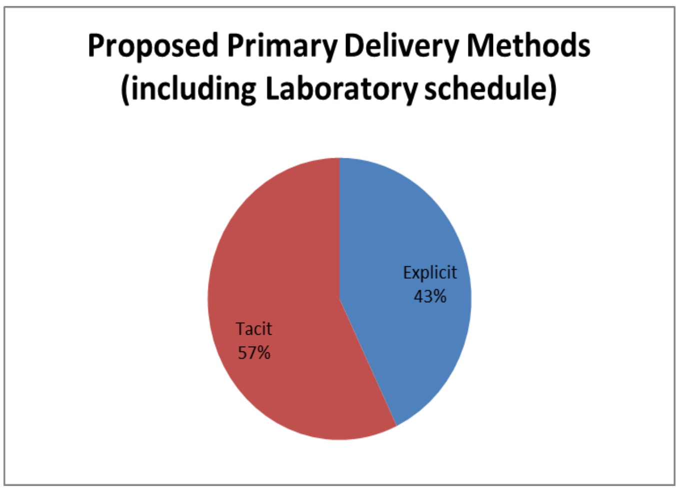


**Figure 4: Proposed Delivery Methods (Including Lab)**

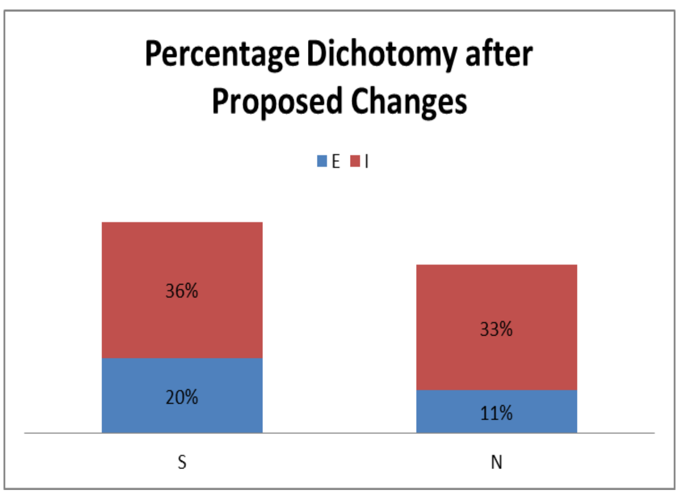


**Figure 5: Proposed Dichotomy Changes**

A more thorough and quantitative feedback will be achieved during the execution of the course once all changes are implemented. Currently, the course instructors utilize daily "one minute feedback" forms. These forms, provided to a random sample of the students each class period, ask the sample to, in their own words, (1) identify the main point of the lesson, (2) identify the most interesting thing covered, and (3) identify the "muddiest" point of the lesson. Comparing and contrasting past feedback forms with the future course will assist this assessment team in identifying whether the changes made to the course are more inclusive to a broader range of preferred learning styles.

## Conclusion

The civil engineering students at the USCGA have incredible demands placed on their time. As such, they are forced to prioritize their efforts on a daily basis. As instructors, our goal is to maximize their retention of our course material in a stringent engineering curriculum surrounded by military demands. The goal of this assessment is to determine how to present material in a manner that most benefits the students. To accomplish this objective, lesson delivery methods were varied based on MBTI personality indicators and explicit vs. tacit learning styles. Ideally, existing and proposed changes will further excite students about the course material providing the ability for the course to reach a broader base audience. By redesigning a "boring" required course and improving the appeal of the material, the intent is to enhance student retention of basic knowledge in a professional setting. Further evaluation of the process will take place in the fall semester of 2015 once all of the changes have been implemented.

## Keywords

Pedagogy; Learning Types: Civil Engineering; Undergraduate

## References

1. The United States Coast Guard Academy. *ABET Self-Study Report for the Civil Engineering Program* New London, CT: The United States Coast Guard Academy. June 25, 2013.
2. Myers, Isabel Briggs. *MBTI Manual: A Guide to the Development and Use of the Myers-Briggs Type Indicator Instrument*. 3rd ed. Mountain View, Calif.: CPP, 2003. 3. Print

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# Instructor-Developed Course Concept Maps Used to Contextualize Material

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## Abstract

During a semester, students often focus on the individual class lectures and topics, failing to see the global picture of the course material. However, with the aid of a concept map provided by the instructors on the first day of classes, and referred to throughout the semester, students may improve their "big picture" understanding of the course. For example, in the Ship Structures course taught at the U.S. Coast Guard Academy, nearly half of the lectures are devoted to designing against the failure mode of yield (19 lectures), while the modes of buckling, and fatigue and fracture have only a few lectures (3 and 2 lectures, respectively). Students previously misunderstood that yield was "more important" and did not recognize that there are other failure modes that must be checked for in design. An instructor-developed concept map was used to help students see that, despite the large number of lectures required to fully understand yield as a mode of failure, it was equally important as the other failure modes. This paper outlines the development and implementation of three concept maps: Dynamics, Fluid Mechanics, and Ship Structures.

## Keywords

Concept Map, Mind Map, Dynamics, Fluid Mechanics, Ship Structures.

## Inspiration

After teaching several courses (Dynamics, Fluid Mechanics, and Ship Structures (co-taught)) all for a second time, the author recognized that many students couldn't classify the topics they had learned. The knowledge was too compartmentalized, and the global topics eluded the students. This was as expected since this was the first time the students had been exposed to this material. However, when the final exams of all three courses require combining information in a comprehensive exam, the inability to understand what topics to consider was proving problematic. All three courses are also prerequisites to other courses in the engineering curriculum. In an attempt to have students learn the "big picture" coincidentally with the lecture topics, the author referenced what had already been implemented in the U.S. Coast Guard Academy course Mechanics of Materials: a concept map[2,3].

Concept maps were introduced into science and engineering by Novak and his research group at Cornell in the 1970s[9]. Fang[5] succinctly defined concept mapping as a "graphical representation" showing "how individual concepts are related to and connected with one another to form large wholes". Concept mapping has been used as a way to "organize and represent knowledge"[10].

Students often miss the overall concept of a course when focusing so much on each individual lecture and problem. A concept map helps with the "big picture" of the course[2,4]. Ellis et al.[4] went on to describe student learning as follows:

> "Because they do not organize their knowledge in a way that facilitates understanding, retrieval and application, they are often unable to apply their knowledge to situations differing from those studied in class. Concept maps are pedagogical tools that help students structure learning in useful ways."

The concept map can then serve as a "scaffold" to learning[10]. This aids in the learning process since many engineering courses take a "bottom-up" approach to the material, with increasing difficulty, so without that "scaffold" students do not recognize how to connect the "incremental bits and pieces" of the material they are learning to the bigger picture[4].

Anecdotally, one student was willing to admit after the Ship Structures final exam that they thought they only had to check for failure due to yielding and not buckling or fatigue and fracture. When further probed, it was recognized that with so much of the course devoted to the failure mechanism of yield (19 lectures) versus the a total of 5 devoted to the other failure modes, students were missing the larger picture and presuming length of time to properly cover a topic was directly proportional to the importance of the topic in comparison to the rest of the course. Many other students shared this one student's perspective on the skewedness of the lecture topics.

In Dynamics, many students failed to recognize that there were three techniques being taught in Kinetics (Newton's Second Law, Work and Energy, and Momentum) that could all be useful in solving a problem, and often any one could be used to get to the same results. Each topic was viewed as separate by the students, and the overall interchangeability of topics was lost in the learning process. Likewise, in Fluid Mechanics, differential versus integral approaches, although both taught, were not viewed as parallel approaches to conservation of mass or momentum. Despite the use of the terms "Conservation of Mass" and "Conservation of Momentum" in the text and lectures, students failed to see the analogy.

It was decided to use an instructor-developed concept map over student developed after reviewing several statements as to the ability of students to develop a meaningful map during first exposure to material. Egelhoff et al.[3] and Egelhoff and Burns[2] found that student-created maps were riddled with misconceptions, missing core topics, and missing linkages. Students would also see the topics as "disjointed and unrelated" [3]. The linkages, therefore, needed to be drawn for the students. Egelhoff and Burns[2] hypothesized that a "common" concept map provided by the instructors would be effective at teaching and reviewing topics for the course of interest. Ellis et al.[4] reiterated that an expert (instructor) making a concept map for students makes the experts understanding of the material more evident and helps the students to better understand the structure of the knowledge as such. Along with providing a "big picture" and structure for the course, a concept map can aid in dispelling misconceptions that students have going into a course. With the linkages already explicit in a concept map, the knowledge structure is withheld and misconceptions dispelled[4].

Table 1: Dynamics course topics in order of presentation, with number of lectures devoted to each topic.

| Topic | No. Lecture Hours |
|---|---|
| Particle Kinematics | 6 |
| Particle Kinetic | 8 |
| Rigid Body Kinematics | 6 |
| Rigid Body Kinetics | 10 |
| Vibrations | 7 |

Table 2: Fluid Mechanics course topics, not in order of presentation, with number of lectures devoted to each topic.

| Topic | No. Lecture Hours |
|---|---|
| Fluid Characteristics | 5 |
| Statics | 4 |
| Conservation of Mass | 1.5 |
| Conservation of Momentum | 7.5 |
| Conservation of Energy | 16 |

Table 3: Ship Structures course topics in order of presentation, with number of lectures devoted to each topic.

| Topic | No. Lecture Hours |
|---|---|
| Geometric Properties | 3 |
| Loading | 2 |
| Yielding | 19 |
| Buckling | 3 |
| Fatigue & Fracture | 2 |

## Development

Each concept map was developed using the course description, outcomes, schedule, and textbooks. It was decided that for each concept or equation, an image would be used alongside. Images are "powerful memory enhancers for most engineering students"[3].

Dynamics was by far the most approached course for a concept map by other institutions. Fang[5] introduced a "Tree of Dynamics" to encourage students to look for the linkages between topics of this challenging course. Fang[5] correctly stated that Dynamics is often found to be one of the most challenging courses in undergraduate engineering with its numerous fundamental concepts. This leads to students failing to know what concepts to apply and when[5].

The author first used the schedule of lectures (summarized in Table 1) to develop a draft of the Dynamics concept map. She then shared this with the other instructors of the course. Another instructor already showed his students a Dynamics "grid", showing the flow of the course with arrows from particle kinematics to particle kinetics, then back to kinematics of rigid bodies

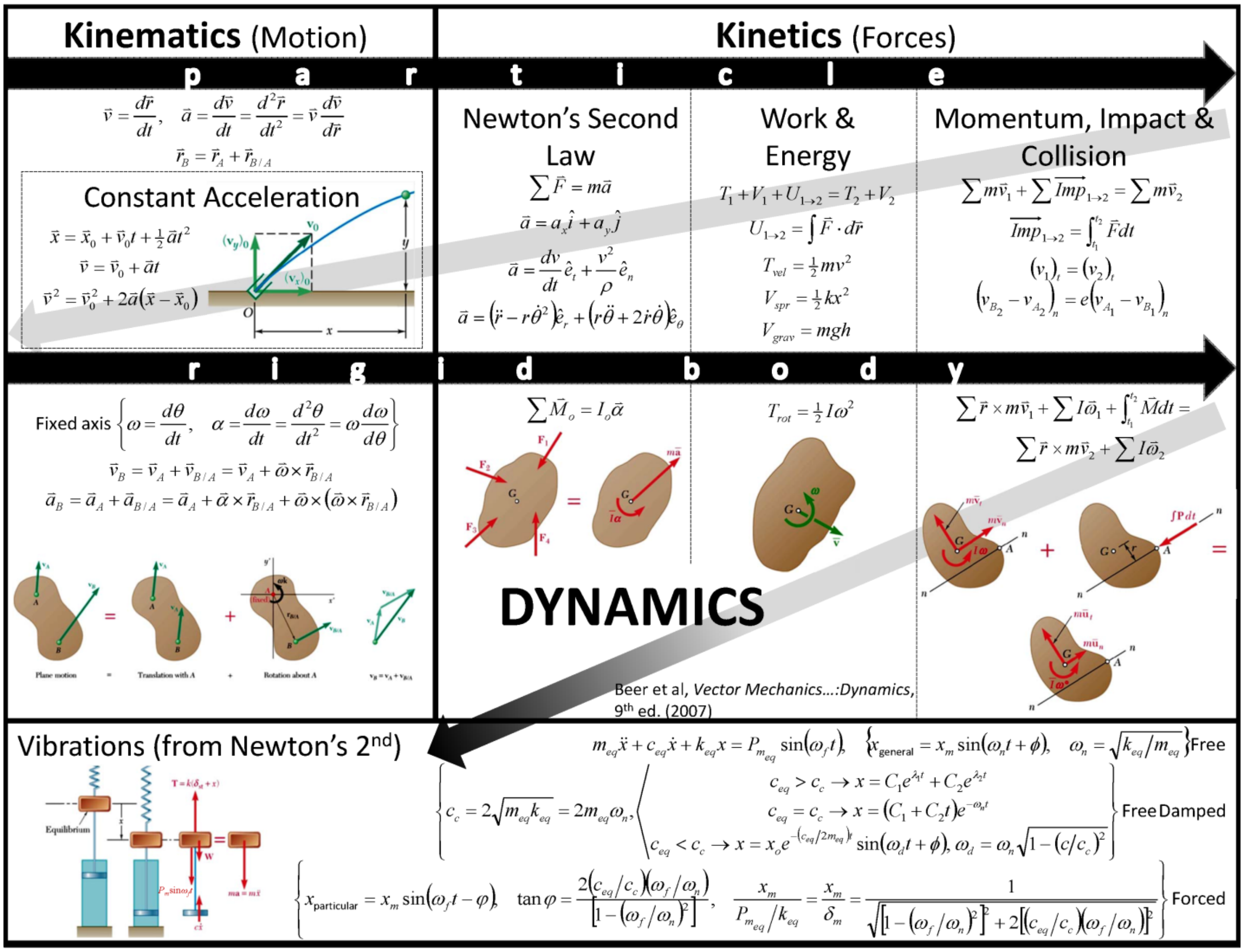


Figure 1: Instructor-developed Dynamics "Concept Map" derived from course topics (many figures borrowed from Beer et al.[1]).

before continuing on with kinetics of rigid bodies, and concluding vibrations. The draft concept map was then overlaid on this grid to unify these concepts and provide the concept map with more structure. The result is shown in Figure 1.

In Fluid Mechanics, some subjects incorporate multiple topics, and some topics were introduced in multiple formats (e.g. integral and differential forms of the Conservation laws). The topics listed in Table 2, then, are often revisited, particularly conservation of energy, which is started with Bernoulli's Equation, and then finished when pipe losses have been covered towards the end of the semester. The resulting Conservation of Energy equation is often referred to as "Super Bernoulli" by the author to convey this connection to the root equation. The most complete form of the equations is used for simplicity, as seen in Figure 2.

Ship Structures was definitely the most interesting to approach, as some topics would occupy such a small percentage of the overall lecture content, such as two days towards the end of the semester being devoted to fatigue and fracture, yet the importance of this topic as a failure mechanism is no less than the 19-lecture topic of yield (summarized in Table 3). The resulting concept map (Figure 3) was significant to the author as it allowed her to become the expert in a

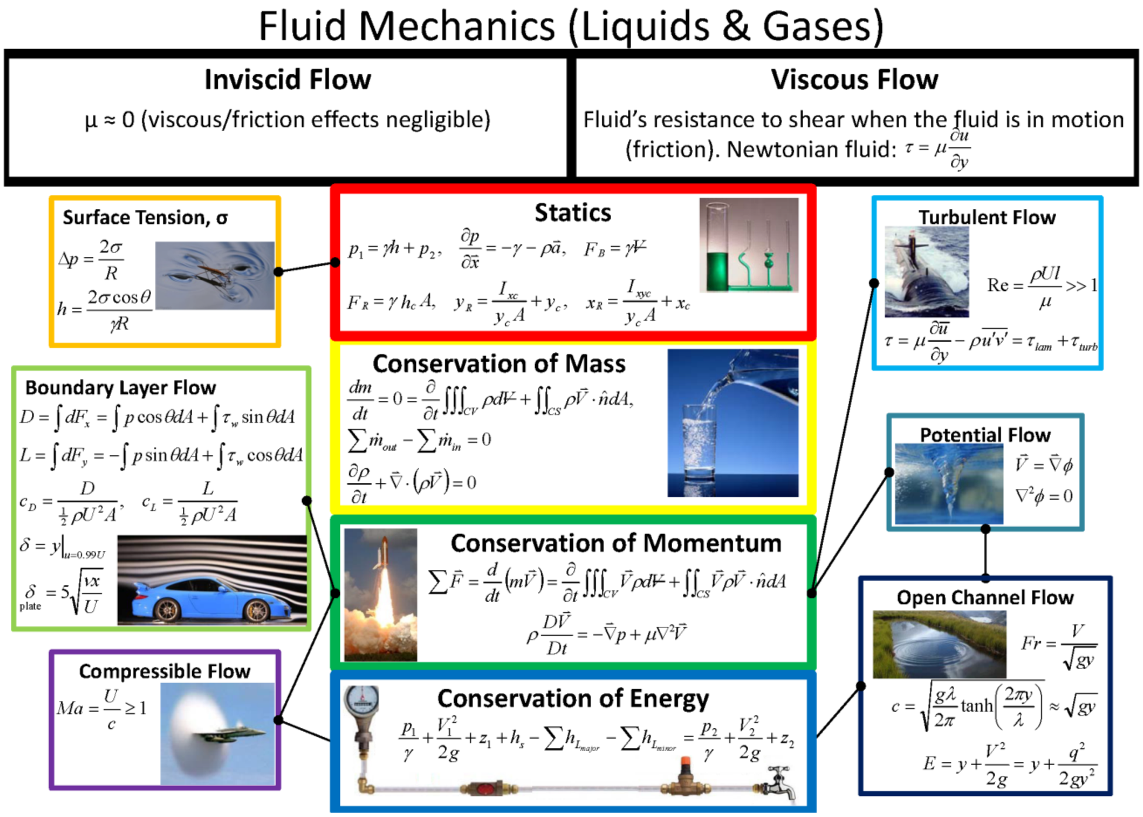


Figure 2: Instructor-developed Fluid Mechanics "Concept Map" derived from course topics.

field that was tangential to her field of expertise and had only co-taught the course, conveying knowledge to the learners as described by Ellis et al.[4].

Although textbooks are used in particular for the concept maps for Dynamics and Ship Structures, the required text for each course could change but the concept map would remain unchanged. It transcends the textbook. Additionally, each equation or figure need not be complete as they are supposed to trigger the use of the actual equation or table or whatever resource is being referenced[2].

## Implementation

Each concept map was printed out in large format and placed into a poster frame, hung inside the classroom. Additionally, it was included in the hardcopy and electronic copies of the syllabus and course schedule. As recommended by McKeachie and Svinicki[8], the concept map is introduced on the first day of class, giving students an overview to the subject matter, although this is an instructor-developed concept map rather than a student developed map.

The concept map is referred to throughout the semester. It is particularly useful when reviewing for exams as well as when a new concept is being introduced. It helps to contextualize the course material and track progress through the course.

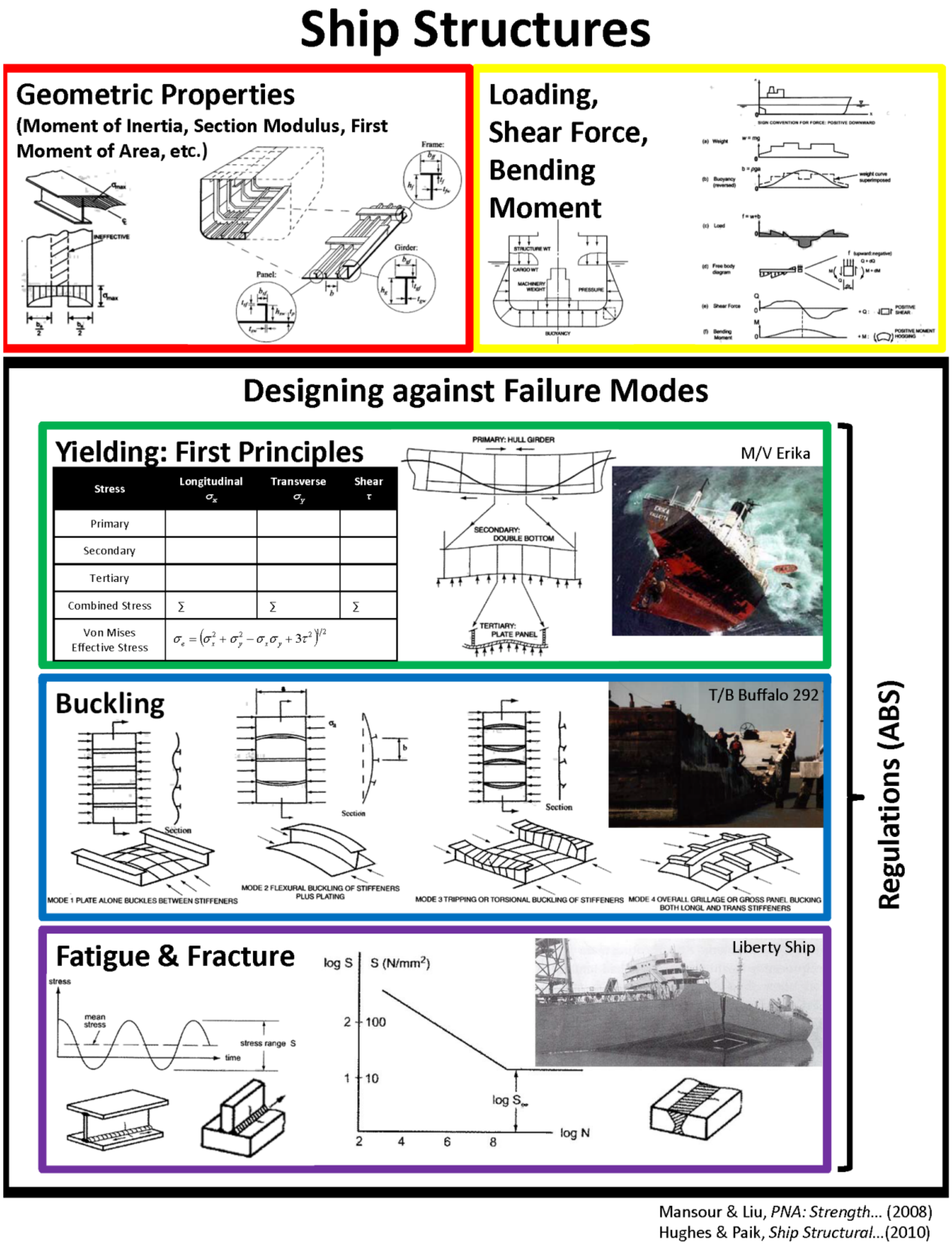


Figure 3: Instructor-developed Ship Structures "Concept Map" derived from course topics (many figures borrowed from Hughes and Paik[6]; Mansour and Liu[7]).

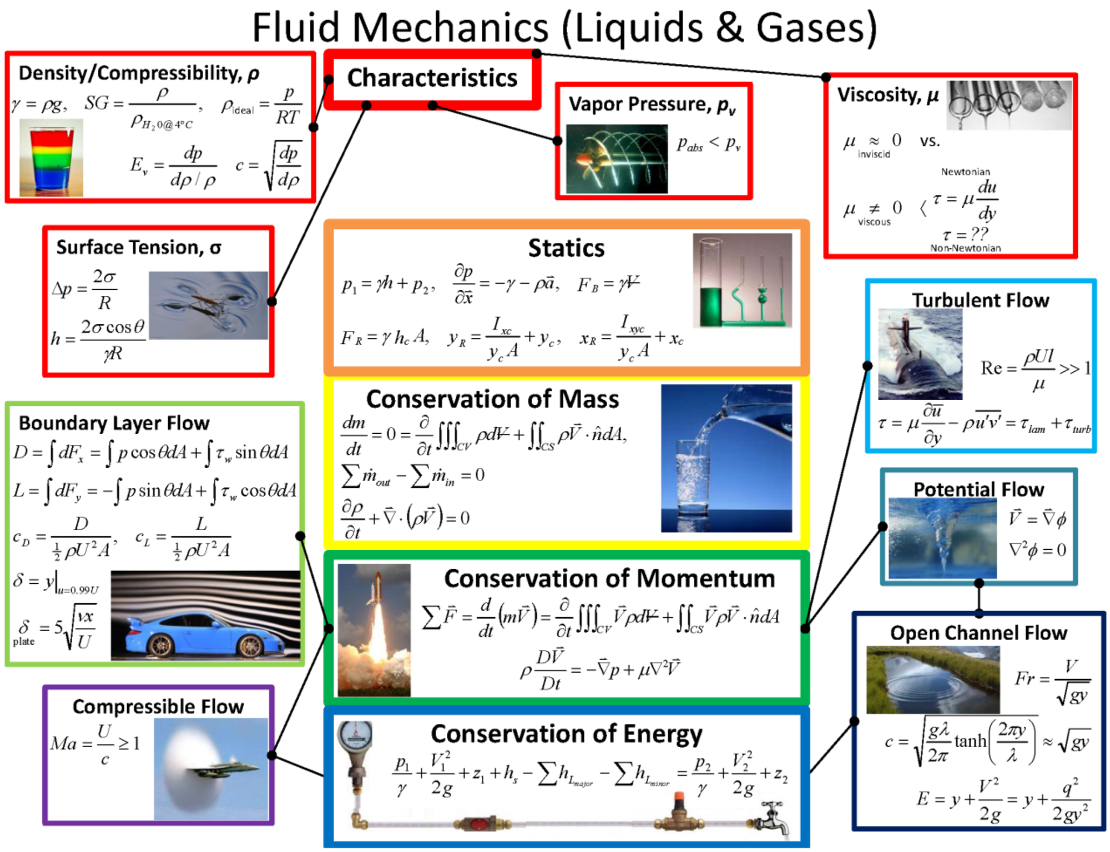


Figure 4: Revised instructor-developed Fluid Mechanics "Concept Map" derived from course topics with continuous improvement efforts.

In addition to helping to place the course in context, it has also helped to create more clear breakpoints for the courses. In particular, in the Dynamics course, there were previously three or four exams throughout the semester, with odd break points in the middle of particle and/or rigid body kinematics. However, having a clear concept map for the course with 5 specific sections, a five-exam format was implemented successfully into the course.

The first semester the concept map was used in Fluid Mechanics, students had the opportunity to make their own concept maps even after viewing the instructor-provided map. There were very interesting results, such as a game board format, but none showed the understanding of interrelationships shown on instructor-developed map, and there wer often omissions or misconceptions present, just as found by Egelhoff et al.[3] and Egelhoff and Burns[2] and Fang[5].

There does appear to be an issue where students may be able to read the concept map on the first day, but they are not able to understand it until the material has been fully presented at the end of the course. This was found to be true by Egelhoff and Burns[2] as well, where Electrical Engineering students who had never seen the concept map before were confused when using it for a general Fundamentals of Engineering review, whereas students in other majors that had seen the concept map before found it very useful. It appears that a one-page course summary in the form of a concept map, despite the simplicity, does not become an effective tool until the concepts have been introduced throughout the semester.

However, referring often to the posters of the concept maps in the classroom did allow students to see how far through the course they were progressing, and mentally noting as they went along how much of the concept map now became significant and meaningful to them. The posters were also left visible during the final exams to serve as a "cheat sheet" for those that recognized the value.

## Conclusion

Each concept map is considered a work in progress; there is always room for continuous improvement. The development of each concept map is an iterative process[4]. Just the reflection provided by writing this paper allowed for some further inspirations for the Fluid Mechanics map, particularly in the Inviscid vs. Viscous Flow, broadening this to the subject area of Fluid Characteristics as shown in Figure 4.

The concept maps have now been in use for three iterations of each course, and have become an integral part of the class. Fewer students have questions about how each concept fits into the big picture of the course, and students no longer express tunnel vision when trying to understand the importance of one topic over another or the interrelatedness of topics.

## Disclaimer

Elizabeth MH Garcia is a professor of Naval Architecture and Marine Engineering at the U.S. Coast Guard Academy. The views here are her own and not those of the Coast Guard Academy or other branches of the U.S. government.

## References

1 Beer, Ferdinand, E. Russell Johnston Jr., Elliot Eisenberg, and Phillip Cornwell, Vector Mechanics for Engineers: Dynamics, 9th Edition, Hughes McGraw-Hill, 2009.

2 Egelhoff, C.J., and K.L. Burns, "A Heuristic to Aid Teaching, Learning and Problem-Solving for Mechanics of Materials," Proceedings of the 118th ASEE Annual Conference, Vancouver, 2011, AC 2011-1261.

3 Egelhoff, Carla J., Nathan Podoll, and Kassim Tarhini. "Work in Progress–A Concept Map for Mechanics of Materials." Proceedings of the 40th ASEE/IEEE Frontiers in Education Conference, Washington, DC. 2010.

4 Ellis, Glenn W., A. Rudnitsky, and Becky Silverstein. "Using concept maps to enhance understanding in engineering education." International Journal of Engineering Education 20, no. 6, 2004, 1012-1021.

5 Fang, Ning, "Enhancing Students' Understanding of Dynamics Concepts Through a New Concept Mapping Approach – Tree of Dynamics," Proceedings of the 119th ASEE Annual Conference, San Antonio, 2012, AC 2012-3345.

6 Hughes, Owen F.,and Jeom Kee Paik, Ship Structural Analysis and Design, SNAME, 2010.

7 Mansour, Alaa, and Don Liu, The Principles of Naval Architecture Series: Strength of Ships and Ocean Structures, SNAME, 2008.

8 McKeachie, Wilbert J. and Marilla Svinicki, McKeachie's Teaching Tips, 12th Edition, Houghton Mifflin Company, 2006.

9 Novak, Joseph D. "Concept mapping: A useful tool for science education." Journal of Research in Science Teaching 27. no. 10, 1990, 937-949.

10 Romance, Nancy R., and Michael R. Vitale. "Concept mapping as a tool for learning: Broadening the framework for student-centered instruction." College Teaching 47, no. 2, 1999, 74-79.

## Elizabeth MH Garcia

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# The Role of Undergraduate History of Engineering in the Formation of Engineers: A New Interdisciplinary, Experiential Approach

**Michael Geselowitz and John Vardalas**

*IEEE History Center at Stevens Institute of Technology*

## Abstract

In the fall of 2014, the authors offered a new course on the pre-modern history of engineering and technology that integrated traditional lectures in history with hands-on engineering labs. From writing on clay tablets, Roman arches, sundials, sand clocks, the students were given an opportunity to appreciate the challenges of problem solving in different historical contexts. Rather than require students to write the standard history term paper, we assigned a term project to study the relationship of design to performance in ancient naval vessels in the Aegean. The students were challenged to make connections between their hands-on experiences and the larger historical and geographic contexts. In other words, interdisciplinary, experiential learning was applied not to the technical component of engineering education, but to the societal context component. The preliminary results were encouraging. Plans are underway to adjust and re-offer the course, and to disseminate it more broadly.

## Keywords

History, society, laboratory, engineering, education

## Background

As the authors have discussed previously[1], the EC2000 Standards of ABET require that students receiving the bachelor's degree "understand the impact of engineering solutions in a global, economic, environmental, and societal context, while other national bodies have similar standards[2]. We argued that history of technology and engineering, rather than ethics or economics—the common non-engineering courses taken by engineers—is the ideal lens through which to address ABET's recognition that that, by its definition as the application of scientific knowledge to the solution of real-world human problems, engineering must respond to changing economic, political and social contexts.

From 1990 to 2014, The IEEE History Center was located at and formally co-sponsored by Rutgers, the State University of New Jersey. At Rutgers, the IEEE History Center was part of the School of Arts and Sciences and was affiliated with the History Department. Rutgers engineering students are required to take expository writing, and four completely open "humanities/social science electives," and a one-credit senior seminar of "professional ethics" (normal courses are 3-credit).

At the same time, the authors themselves—Ph.D. social scientists with undergraduate technical degrees—taught separately and together with each other and other historians a two-course sequence on the history of technology and an introduction to science, technology and society" with a strong historical component. More specialized history of technology courses have also been given. Owing the structure of scheduling and curriculum by Rutgers, these courses were seldom taken by engineering students. Our previous paper cited above and another paper co-authored by one of us (Geselowitz)[3] presented results of a web survey and an email survey of engineering schools that history of engineering courses were not widely available to engineering students.

As reported in the earlier paper, in 2009 one of us (Vardalas) had an opportunity, as a visiting lecturer, to teach a course on the history of technology at the University of California, Merced (UC-Merced). UC-Merced is the tenth and newest UC campus (it opened in 2005, the first in 40 years; UC Santa Cruz and UC Irvine were added in 1965). As "the first American research university of the twenty-first century" (as it bills itself), UC-Merced is committed to interdisciplinary practice and to performing as a network. Still early in its life, UC-Merced had an organizational culture that was conducive to working across traditional faculty boundaries than at most long-established universities such as Rutgers. In this collaborative environment, Vardalas, with assistance of Geselowitz and based on their collaboration at Rutgers, was able to work with both the School of Social Sciences, Humanities & Arts and the School of Engineering to create a course that served both their needs; making social studies and humanities students aware of the role of technology in the story of humanity, and providing engineering students with a course that truly responds to the ABET 2000 requirement of presenting the process of engineering in a cultural context. This one-time offering was an experiment. It took the unusual step of incorporated laboratory exercises into a basically humanities and social science course. We are not aware of this being done anywhere else in any sustained manner ("Stuff of History" at Olin College, cited by the NAE "Educating the Engineer" report[4], is co-taught by and engineer and historian, but consists of lectures, discussions and papers; "Engineering in the Modern World" at Princeton, which is also team-taught and does incorporate both papers and problem sets, may be the only even remote predecessor).

The challenge in creating the laboratory component was to identify the readily available infrastructure and human expertise at UC-Merced around which one could build hands-on activities. The combination of experts in the geo-chemistry and physics of clays and the presence of a kiln on campus led Vardalas to the design of a series of labs around the role of bricks in the Roman Empire. After a brief lecture on clay soils and the role of heat in transforming clay materials, we asked the students to identify and dig up the best available materials for bricks. To help them prospect for the brick material, they were given an iPhone app that combined locational data with an underlying California soil map. Then they had to experiment with the heating techniques needed to produce a brick. These various tasks were spread out of 4 weeks independent of class time. The students learned more by failure than by success. By answering the question "What went wrong?" the students better understood the challenges that the ancients faced when they used heat to transform matter.

The students then had to comment on the economics and industry of brick making in Rome and the role of bricks in the Roman architecture and civil engineering. The students were also asked to extrapolate their insights to other ancient ceramic products. The students were enthusiastic about this hands-on experience.

In 2014, the IEEE History relocated to the Stevens Institute of Technology. As an institution focusing almost exclusively on the formation of engineers and related professionals, but with a vibrant and dynamic humanities faculty whose mission is to enrich the educational experience of its undergraduates and to create bridges between the humanities and social sciences, housed in the College of Arts & Letters (CAL) and engineering, Stevens is an ideal laboratory to explore the role of history in engineering education. Its small size an private nature afford it some flexibility lacking from a large, public research university such as Rutgers or even, as it undergoes growing pains, UC-Merced.

Based on earlier research and the experiment at UC-Merced, in the fall of 2014, the authors offered a new course on the pre-modern history of engineering and technology that fully integrated traditional lectures in history with hands-on engineering labs. It was to be a pilot, with a limited number of labs, to prove the value of the approach. The labs had two goals: to expose the students to problem-solving in different historical contexts; and to relate this problem solving to the broader narrative of human history.

## Structure of the Course

The course met once per week for two-and-half hours over 14 weeks. One of these sessions was the midterm (the final was given outside class during finals period) and the last class was the student presentations of the term project (more on that below). Two of the sessions were devoted to small stand-alone labs, and third to introducing both the historical and engineering aspects of the term project. The labs were conducted in groups but individual lab reports were due. In addition, hands-on demonstrations were distributed throughout the lectures.

There was no textbook, but book chapters and articles were made available on-line. For every class except the first, last and midterm, there were a number of required readings and two one-page reading reports were due (on reading report on the days when lab reports were due).

The backbone of the course was the term project. As with the two labs, the nature of the term project had to revolve around the physical and human resources readily available to us at Stevens. In this process, the engagement of the Dean of Engineering was essential.

Stevens has a top-rated program in naval and ocean engineering, which includes very sophisticated tank-testing facilities. Since ancient maritime trade and naval power was an important theme in the lectures, we decided to have the students use modern techniques to investigate the performance of ancient ships. Iconographic evidence shows ancient vessels with very long protruding bows, long before the idea of a ram came about. The technical heart of the term project lay in the question, “Did these bows serve a purpose?” 3-D CAD modelling and computer manufacturing were used to produce a 4 ft. model of the hull. Then it was tested in a large tank a various speeds.

We were quite fortunate to have an archaeologist, naval historian of the ancient world, and two naval architects help the authors frame a student project that addressed a meaningful historical issue without making unrealistic demands of the students.

The grading rubric was:

Reading reports (20 @ 1 pt each) 20%
Lab Reports (2 @ 5 pts each) 10%
Mid-Term Exam 20%
Final Exam 20%
Class Project (team grade) 25%
Class Participation 5%

An anonymous questionnaire to all of the students insured that all students participated relatively equally on the project, justifying the team score.

## Desired Learning Outcomes

The learning goals for the course were defined as follows:

Through a broad sweep of history, the student will, by means of concrete examples drawn from agriculture, materials, communications, power & energy, transportation, and from the military systems learn to…

- describe the different ways engineering has transformed human existence;
- analyze how political, military, economic, social, and religious objectives have guided the design and use of technology
- evaluate the importance of geography in framing engineering opportunities and constraints
- illustrate the roles of serendipity and unintended consequences in the interplay of technology and society
- differentiate the different ways technological know-how moves across territorial borders and cultures
- pin-point examples of the varying causal relationships between the advance of scientific knowledge and technological progress
- compare and contrast, from a longer term perspective, continuity and change in the story of technology, and be able to discuss the concept of “technological lock-in”
- identify instances of both the diversity and commonality in the broad history of technological change

Note that although the course drew on specific examples, there was not a goal for the students to learn any specific historical trajectories of any specific technologies (although we hope that some of this rubbed in), but rather for the historical perspective to elucidate the relationship between technology and other aspects of society.

## Results and Future Plans

Ten students enrolled in the course, generally third- and fourth-year students equally divided from engineering disciplines and science disciplines (at Stevens science and engineering students are in the same school, the Charles V. Schaefer, Jr., School of Engineering & Science; no students from the small College of Arts & Letters enrolled in the course). The authors were open with the students about the course being experimental and maintained an open conversation about the progress of the course.

Everything went extremely smoothly and the feedback was positive throughout. The students threw themselves into the term project, and the final presentations were opened to the Stevens community; among the attendees were the Provost. The presentations were unusual in that the students had to pretend that they were presenting to the Athenian Assembly on the eve of the Peloponnesian War. They had to convince the Assembly to spend a lot of money on Trireme R&D. Their arguments had to combine engineering know-how with sensitivity to the political, economic, and military concerns of Athens. The students did an outstanding job, one team even postered the campus and came in costume. It must be stressed that the project

As a result of these presentations, and on the recommendation of the outside consulting scholars, the authors were able to obtain funding to hold a symposium on the engineering and historic impact of the Greek trireme, at which the outside scholars spoke and the students re-presented their term papers in a poster session. The results of the symposium have led us to think that there is a publishable paper in the term project results.

Stevens also conducted its standard quantitative student assessment. Admittedly the sample size is small, but the students almost unanimously felt that they had achieved all of the course specific learning goals. On some of the questions asked of all CAL courses, however, we did less well. For example, only 60% of the students responded positively to the question, "Did the course increase your awareness of the ethical responsibility…of your future profession?' Although as we stated above and in our previous papers we fell that history is a broader approach to social impact than ethics, if students are going to take a limited number of humanistic courses the ethical component needs to be addressed in every one. Likewise, although as historians we feel that "the past is a foreign country), the diversity question (Did the course increase your awareness of cultures and societies other than your own?) also only scored a 60% positive result. Students apparently did not receive the message that ancient, classical and medieval societies are also non-Western in the sense it is understood today. It is critical we address this as well, as one of the goals of the course was about the differing nature of technology in different cultural settings.

Overall, the results have led the authors and the university to feel that it is important to offer this course on an ongoing basis, and it will next be offered in spring 2016 (in the meanwhile, other IEEE History Center staff are teaching more traditional history of technology courses).

The results have also led the authors to wonder if conditions might exist elsewhere, beyond Stevens (and perhaps UC-Merced) to adopt such an interdisciplinary course. This presentation at an ASEE Section meeting is an attempt to begin that conversation.

## References

[1] Geselowitz, M., and J. Vardalas, "Using History of Technology to Promote an Understanding of the Impact of Engineering Solutions among Engineering Students," *Proceedings of the 118th ASEE Annual Conference and Exposition*, 2011

[2] Criteria for Accrediting Engineering Programs, 2010; accessed on the web on 26 July 2010 at http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2010-11%20EAC%20Criteria%201-27-10.pdf; compare, for example, the 2010 Standard for Professional Engineering Competence of the UK Engineering Council. Which states that graduates of accredited programs must "appreciate the social, environmental, ethical, economic and commercial considerations affecting the exercise of their engineering judgement"; accessed on the web on 26 July 2010 at http://www.engab.org.uk/ecukdocuments/internet/document%20library/AHEP%20Brochure.pdf.

[3] Geselowitz, M., and L. Feisel, "An On-Line Course in the History of Engineering and Technology," *Proceedings of the 120th ASEE Annual Conference and Exposition*, 2013.

[4]Committee on the Engineer of 2020, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, National Academies Press, 2005.

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# The 'T-Shaped' Learning Experience at Worcester Polytechnic Institute

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## Abstract

As the 21st century progresses, the engineering profession faces many challenges that have created a demand for engineers with 'T-shaped' skills. These 'T-shaped' skills not only require depth of knowledge in the field but also a breadth of skills such as proper communication, leadership, and creativity. This paper presents the experiences of Worcester Polytechnic Institute (WPI) in introducing 'T-shaped' skills to students through curriculum and internship opportunities. The methods by which the Civil Engineering department at WPI weaves 'T-shaped' skills into an NSF-funded Research Experience for Undergraduate Research (REU) program, high school internships, and senior design projects are discussed. Assessment of these efforts showed improved depth (learning concepts/knowledge) and breadth (application of knowledge, communicating the knowledge, and presentation of knowledge) of the students in the programs.

## Keywords

'T-shaped' skills, NSF-funded REU program, high school internships, senior design projects

## Introduction

The development of engineering education has evolved over time[1]. In the nineteenth century and in the first half of the twentieth century, engineering education put major emphasis on "hands-on" experiences. As the remaining second half of the twentieth emerged, the paradigm shifted towards including more science and mathematics in the curriculum. However, entering into the twenty-first century, further changes have become necessary. Curriculums across higher education schools are adjusting to the need for students to attain knowledge beyond the traditional science and mathematics skills. Rather they are clearly defining the need for engineering students obtain 'soft skills' such as communication, leadership, and creativity skills[2]. These changes have led to the twenty-first century's need for the 'T-shaped' professionals.

The term 'T-shaped' refers to a professional who obtains both depth (the vertical line of the T) and breadth (the horizontal line of the T). Depth is the knowledge one has in the specific area of study and breath refers to 'soft skills' such as collaboration and communication. Professionals with 'T-shaped' skills are more likely to be better problem solvers and excel within their profession[3-4]. This emerging necessity has led to the development of incorporating 'T-shaped' skills within the engineering education curriculum[5].

Worcester Polytechnic Institute (WPI) was founded in 1865 with the mission of educating "talented men and women in engineering, science, management, and humanities in preparation for careers of professional practice, civic contribution, and leadership, facilitated by active lifelong learning"[6]. In doing so, WPI has designed the school's curriculum to achieve these goals by creating the *WPI Plan*. The *WPI Plan* takes on project-based program in addition to the required coursework. There are two major projects necessary for all students. The *Major Qualifying Project* (MQP) allows students to investigate problems that they may face within their profession. This is typically conducted during the student's senior year at WPI. It allows the students to delve deeper into a certain practical issue within their major. This may involve collaborating with a company, a redesign of a structure, or research. The *Interactive Qualifying Project* (IQP) is a project that deals with societal issues and technology. Typically students complete the IQP during their junior year at WPI where they can travel abroad and work with on an issue that the country/region may be facing. Additionally, students are required to complete a Humanities and Arts Practicum/Seminar generally during their sophomore year. Since these projects are traditionally group projects, this encourages collaboration, leadership, communication skills, etc. The projects which WPI has integrated within its curriculum are a technique and method of educating students to be exposed 'T-shaped' skills and eventually become 'T-shaped' professional.

The Civil Engineering department at WPI not only uses these required projects to encourage 'T-shaped' skills amongst their students, but also incorporates other programs to promote such skills to various students including non-WPI students. The department has a high school internship program where the high school students shadow and assist a graduate student with research. Also, the department hosts an NSF-funded Research Experience for Undergraduates (REU) program where local undergraduate students work on a research project. These programs all have a commonality where the 'T-shaped' skills are integrated within the student's experience.

This paper discusses methods of which the Civil Engineering department at WPI incorporates techniques into the programs they are involved in to expose the students to 'T-shaped' skills. Since the programs generally take place in a research lab environment, this paper will refer to the experiences regarding to research. The paper is grouped into three sections. The first section discusses techniques for teaching depth of knowledge, the second section describes the methods of incorporating breadth, and lastly the outcomes of these experiences. Assessment of these efforts showed improved depth (learning concepts/knowledge) and breadth (application of knowledge, communicating the knowledge, and presentation of knowledge) of the students in the programs.

## Depth

When the students begin a project/program involving research, it is vital to clearly define and outline the research that is to be conducted[7]. This will ensure that the students understand what is being investigated and why. In order to accomplish this task for the REU students in the Civil Engineering department at WPI, the two major steps are carried out. First, the students undergo a 'crash course' on the research that they will be involved in and conduct a background/literature review. The following describes both steps.

*'Crash course'*

Prior to the students working in the lab/on a project, a ‘crash course’ is carried out. This involves the mentors (the professor and/or the graduate students who work with the students) to describe the scope of the project that the student is to be involved in. Many times, students are ‘thrown’ into a project and asked to do a specific task. However, many times the student does not fully understand what the project is actually about and thus a deep understanding of the research is not achieved. This ‘crash course’ includes a background on the topic as well as demonstrations. It is important to note that this course is not a traditional course where the subject is taught and then a test is given to assess the student. Rather, a different learning style is carried out where the course is discussion based. By talking to the students, the mentor can gauge the knowledge the student presently obtains on the subject matter and therefore can understand what needs to be explained. For example, when introducing the topic of research of corrosion in concrete structures to the high school interns and REU students, the purpose of researching corrosion of the reinforcing steel within concrete was at first unclear to the students. They did not know that concrete structures had reinforcing steel embedded within. However, by both explaining the reasons and showing the students actual reinforcing steel and concrete samples, they were able to fully grasp the motivation for such research. By including a ‘crash course’ to the program, the mentor can get a good understanding of the student’s knowledge as well as determine the student’s learning style. Therefore this ‘crash course’ can help improve the quality of the research for both the student and mentor.

*Background/literature review*

Once an oral explanation of the project is carried out through the ‘crash course’, the students then begin a literature review. For students to conduct research on a topic, he/she must first understand the problem that is trying to be solved and be aware of the studies that other researchers have previously conducted. This also gives the students exposure to the practical side of research and what a common researcher would have to do in the profession.

The mentor provides articles to the students to read before the start of a project. Since the information that is being studied is usually new to the students, the mentor will read and discuss the paper together to ensure the student understands what is written. Before conducting any experiment in the lab, the students are asked to read and understand the methods and standards that are provided by the American Society of Testing and Materials (ASTM). These standards provide required information related to the materials that should be used for any experiment, the step by step description of conducting the test, and the acceptable errors of the test. Reading these standards give the required information about the materials that students need and the procedures that they should follow to conduct the tests. Therefore, it makes it clearer for them to compare and contrast their results with other studies.

## Breadth

In the engineering and research profession, breadth is critical. Presenting research ideas and results is important since that is how others can know about what is being investigated. This may be done by an oral presentation, a written article, communicating with possible collaborators, etc. Therefore, there are several approaches including weekly meetings, lab work, and preparing reports and presentations which have been included to incorporate these breadth qualities into the programs.

*Weekly meetings*

Once a week the students meet with the entire research group. In the meetings, results are presented and discussed. This allows all members of the group to collaborate on ideas, provide input, and explain future studies. One major benefit to the weekly meetings is that it allows for the students to bring up any questions or concerns and ensures that everyone from the group is on the same page.

*Hands-on approach - Lab work*

The students took on a hands-on approach to the lab work. They prepared samples, ran equipment, and analyzed the results. Their mentors initially worked with the students and taught them the techniques and methods necessary. By having the students produce independent research and results, the students were able to have more of a realistic understanding about research and also gave them a better sense about aspects such as the dimensions, weights, and the general numbers that they are working with.

Moreover, complementary to conducting laboratory experiments, the students recorded and analyzed data. They were taught how to record data and the experimental results in a scientific method. For example, students were provided a lab-notebook and were asked to record all the lab tests and results in detail. This included documenting the date for each experiment, using pen to record data, putting a descriptive notes, etc. This is important since the programs not only strive to provide the technical skills to young engineers and researchers, but also teach them about academic and engineering honesty.

*Preparing reports or presentations*

Presenting research can be just as important as carrying out the research itself. This can be completed through oral or written explanations. In doing so, students are asked to assist in preparing a report such as a journal article on their project. The students can become the co-author of the paper which encourages them to take responsibility and ownership of their project. It also teaches them technical writing skills as well as helps them to further understand their work since they have to explain it in writing.

Additionally, at the end of their program the students are asked to present an oral poster presentation. For the REU program, a poster session was held where each student presented their research (Fig. 1). Guests were able to view the posters as well as ask the students questions and discuss their research. A similar type of presentation is held annually for the senior projects (MQP) and their presentations are judged by a panel of industry related professionals. A poster presentation further encourages and gives the students practice to communicate their findings to those who may not know much about their research.


**Figure 1: REU student present her research on the project presentation day**

## Example Outcome

Results from utilizing both the depth and breadth techniques (‘T-shaped’ skills) that the Civil Engineering department uses has shown to be effective. An example can be drawn from an REU student. This particular student was a sophomore from another university. The student’s knowledge on the assigned research topic was very general prior to the start of the program. As the student began the WPI program following the depth and breadth strategies, the student rose to the task of taking on a large part of the research. The student started contributing ideas and had scientific evidence to back-up the proposed ideas. Also, the student would conduct experiments and analyze the results. The student used the information collected and has become a co-author to an article. Moreover, even after the REU program was completed, the student submitted an abstract on the research conduct at the WPI REU site to a conference. The abstract was accepted and the student attended the conference to present the research. Similar successful outcomes have been seen with other students who have also completed the breadth and depth process which the Civil Engineering department uses at WPI.

## Conclusions

Engineering education changes over time. As for the twenty-first century, the shift has been towards exposing students to a ‘T-shaped’ structure. Schools of higher education, such as WPI, have incorporated these ‘T-shaped’ skills within their program. By encouraging both depth and breadth within a curriculum or program can increase the student’s possibility of success within the student’s future professional career.

## References

1 Ravesteijn, W., E.D. Graaff, and O. Kroesen, “Engineering the future: the social necessity of communicative engineers,” European journal of engineering education, 2006. 31(01): p. 63-71
2 Tryggvason, G., D. Apelian, Shaping our World, John Wiley & Sons Inc., New Jersey, 2012, p.7-8.
3 Donofrio, N., C. Sanchez, and J. Spohrer, Collaborative innovation and service systems, in Holistic Engineering Education. 2010, Springer. p. 243-269.
4 Donofrio, N., J. Spohrer, and H.S. Zadeh, “Research-Driven Medical Education and Practice: A Case for T-Shaped Professionals,” MJA Viewpoint, 2009.
5 Grasso, D., Melody Brown Burkins, J. Helble, and D. Martinelli, “Dispelling the myths of holistic engineering,”Holistic Engineering Education. 2010, Springer. p. 159-165.
6 Worcester Polytechnic Institute, “Undergraduate Catalog”, 2015, p. 3.
7 Gross David, B. Tools for Teaching, John Wiley & Sons Inc., California, 2009, p. 244-248.

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# Educating the Engineering Educator

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## Abstract

Engineering education research largely focuses on student learning to meet industry demands, with little attention paid to faculty. An assumption is that professors get their "training" at graduate school. This may be true of content areas, but most graduate education occurs in large research focused universities. With limited and variable training across institutions, the consensus is that many graduates are ill prepared to be teachers. If our engineering educators are ineffective, they are not helping build a strong foundation for new engineers.

This paper identifies four programs; ExCEEd, organized by ASCE; project Catalyst at Bucknell University; the National Effective Teaching Institutes (NETI) program, and the NSF SUCCEED program. All of these have an underlying mission of providing additional training to develop and retain new engineering professors and help them become effective teachers. This paper provides an overview of these programs, and reflections of the authors' experiences as ExCEEd graduates.

## Keywords

New Faculty; Effective Teaching; ExCEEd Model, Project Catalyst

## 1. Introduction

According to Brent and Felder (2003)[1] "College teaching may be the only skilled vocation that neither requires prior training of its practitioners nor provides it to them on the job". Much of the conversations and debates in engineering education focus on student learning and content development to meet industry demands, with little attention paid to the people who are helping create the new professionals in engineering. A great deal of the literature on the teaching preparedness of new professors has also been focused on the preparation they receive at graduate school. Meanwhile the general consensus is that the level of teacher training received by students at graduate school is not adequate most of the time to make them effective teachers.

The result is that new professors come into academia ill-prepared and often do not have role models to guide them. These professors quickly learn the hard fact that the atmosphere in which they succeeded as graduate students was different from their new environment. Their level of unpreparedness is evidenced as they begin to have more questions than answers about what constitutes effective teaching. In order to fill this large gap and provide some guidance and mentoring for new professors, a number of teaching workshops are organized each year at various locations to provide an opportunity for new hires to enhance their teaching expertise.

This paper examines some of the programs that exist for engineering professors, and are aimed at addressing the challenges that are faced by faculty, particularly in the small institutions whose focus on teaching is different from the large research institutions that provide the doctoral training.

## 2. The nature of graduate studies

Graduate school provides opportunity for students to pursue master's degrees and doctoral degrees. While masters degrees often provide students an opportunity to gain expertise in a specialized field and return to professional practice, a few students continue to earn doctoral degrees. Some of the doctoral students also end up working in industry, but majority proceed with careers in academia. While doctoral programs are pursued in large research universities whose focus is to produce researchers that are able to conduct rigorous scientific studies[2,3], not all academic careers are research focused as other institutions lay more emphasis on teaching[3]. Most of the time, however, graduate programs do not provide adequate preparation for academic careers[2], so only a few graduate students receive any formal preparation in teaching while in graduate school[4].

The environment for the training is thus radically different from the environments in which most of the faculty jobs exist today. These are small public and private colleges, public comprehensive universities, and community colleges. These institutions have different expectations of the faculty they hire. Apart from subject matter and research expertise, the faculty members are expected to be effective teachers and academic citizens[2]. Unfortunately the research component of doctoral education is often emphasized at the expense of the development of broader skills that are needed for success beyond graduate school, particularly in academic careers[3].

In recent years however, there have been a number of national movements to address the shortcomings that exist in the training of doctoral students for academia. Notable among these is the Preparing Future Faculty (PFF) program, which was launched in 1993 by the Association of American Colleges and Universities (AAC&U) and the Council of Graduate Schools (GCS) with an objective of developing new models for preparing doctoral students for faculty careers. Highlights of the new model include preparation for teaching, academic citizenship and research[2,5]. Notwithstanding these national moves to modify doctoral training, PhD students continue to be turned out every year without adequate preparation for teaching.

## 3. The preparation for college teaching

The three broad areas that constitute faculty responsibilities in most universities are teaching, research and service. So the training for graduate students for academic roles cannot be complete if important elements of these three components are not adequately covered as part of the training. Of these three areas of significance, however, teaching is the responsibility that demands most immediate attention and consumes most energy from new faculty[4] because the new faculty are expected to come in as effective teachers[6].

Unfortunately the training received in teaching is often limited and varies from one institution to the other. Even in the same institution it varies from one discipline to the other. While some graduate students have no teaching experience, others serve as teaching assistants engaged only in grading and others teach labs. Some teach a single course and only a few graduate students are independently engaged to teach a few courses, and in many universities engineering students are not often given the opportunity to teach full courses. So only a few doctoral students graduate with reasonable amount of teaching experience. Seeing the significant role that teaching plays in the career of a professor, and also for the fact that majority of doctoral students end up teaching at institutions that lay more emphasis on teaching, it stands to reason that graduate schools are ignoring a very vital of the training that is needed for the success of their students[2,7]. The result is that many graduates are ill prepared to be teachers, and are greatly challenged when they find jobs in universities that expect their new faculty to be effective teachers. And if our engineering educators are ineffective, it means they are not helping build a strong foundation for new engineers. Teaching may also include student advising, supervision of practicums, internships, independent studies and theses. Meanwhile doctoral students are hardly given any opportunities to improve their skills in any of these areas as they are not given the opportunities to mentor students, and often ill-prepared to meet advising expectations[2].

The irony is that even as new faculty are coming in ill prepared for teaching, most institutions are also increasing the emphasis placed on teaching quality. The traditional well-structured lecture format is considered inadequate in meeting the learning needs of students. Many schools expect their faculty to adopt new pedagogies that address the different learning styles and expectations of their students. These new pedagogies include technology, active learning techniques, collaborative learning, flipping the classroom etc. [2]. For doctoral students, these demanding teaching needs could better be addressed by providing them opportunities to teach, after training them in a variety of classroom instructional strategies. These could include new teaching techniques like active learning, field-based learning, etc. When students are offered these kinds of opportunities early enough in graduate school, they will make mistakes and correct themselves as they learn from their professors. Graduate students would also tend to understand the actions of their professors in the classes that they take, and may eventually incorporate those techniques into their classes. Supervised teaching with feedback thus has the potential of helping doctoral students to build competence and confidence in teaching and working with students[2].

## 4. The need for teacher training for new engineering faculty

If colleges and universities expect graduate students to be ready for teaching upon receipt of their degrees, then it is necessary to modify the nature of current doctoral programs to lay more emphasis on teaching as a component of graduate training. However, this could mean putting unprepared graduate students in charge of classes. In some disciplines however, a terminal degree has to be earned before one is considered qualified enough to teach at the college level[6], and this is the reason why graduate students are not allowed to teach college courses in those disciplines. Thus, they will graduate without any instruction or practice in teaching. In recent years however, academic leaders from many fields and disciplines have recognized the need to prepare their faculty and future faculty to become effective teachers[2,8]. A number of universities and colleges have established training centers for the development of their faculty and graduate students. Many academic programs also provide some form of preparatory training programs and orientations for new faculty, even though these vary in quality, content and duration[6,9] . These training programs range from half-day pre-semester workshops to year-long courses on teaching and may cover topics ranging from course design, creating syllabi, classroom management practices, active learning techniques lecture preparation, teaching ethically, student assessment, and course evaluation[6]. Apart from this, there are other training programs that are organized for the training of engineering professors, and notable among these programs are:

- The ASCE ExCEEd teaching workshop,
- Project Catalyst, Bucknell University
- The National Effective Teaching Institutes (NETI)
- NSF SUCCEED Program

All these programs have an underlying mission of providing the additional training needed to develop new engineering professors and help them become effective teachers. After a brief description of the programs, the authors, both graduates of the ExCEEd training workshops will provide a reflection of the impact of this workshop on their own teaching experiences.

Engineering education itself has been through many changes over the years. In the 1970s through 1980s for instance, it became increasingly clear that the theory-oriented lecture type of instruction was no longer productive in meeting both the developmental skills desired by industry and the diverse learning needs of the student population[1] (Felder, 2003). The challenges that confronts the new faculty then goes beyond a lack of adequate preparation at graduate school to include a changing engineering pedagogy that embraces more innovative teaching practices that include aspects of active learning, cooperative learning and the use of technology-based courses. In 1991 the National Science Foundation (NSF) began funding engineering schools to initiate reforms to engineering education. This included the SUCCEED program that initially included eight institutions[1]. The primary focus of SUCCEED was the development and institutionalization of innovative teaching materials and programs, and the assessment of learning outcomes.

### 4.1 Notable short on campus training programs

The SUCCEED model has a faculty development (FD) component that was aimed at a sustainable development for engineering faculty[10]. Also within the FD program is a one week workshop for new faculty on effective teaching and other faculty duties. It also has workshops and seminars for doctoral and post-doctoral students, focusing on areas such as: learning styles, effective lecturing techniques, active and cooperative learning and dealing with common student problems[4].

### 4.2 Project Catalyst, Bucknell University

This teaching workshop is a three-day summer event that has been organized annually at Bucknell University by faculty from the department of Chemical Engineering for the past 13 years. The theme for the workshop is “How to Engineer Engineering Education” and the target group is engineering and science faculty, and graduate students. The workshop is designed to enhance the teaching expertise of participants by receiving instructions on the following activities in an engaging and interactive group environment[11].

a. Writing clear instructional objectives at appropriate cognitive levels
b. Using active, cooperative, & problem-based learning
c. Teaching teamwork and problem solving skills, and
d. Assessing learning outcomes

The culminating event at the workshop is a short PowerPoint based “lecture” by the participants on a topic of their choice. Program instructors and fellow participants then offer feedback.

### 4.3 The National Effective Teaching Institutes (NETI)

The national effective teaching institute is a series of teaching workshops organized every year[1]. NETI-1 is a three-day workshop on effective teaching for engineering instructors, which is held twice each year at universities and colleges, while the Advanced National Effective Teaching Institute (NETI-2) is held every two years. Sponsorship for the program is from the Chemical Engineering and Educational Research and Methods Divisions of the American Society of Engineering Education (ASEE) and funded by participant registration fees. All NETI programs are codirected by three persons: Rebecca Brent (President, Education Designs, Inc., Cary, NC, Richard Felder (Professor Emeritus of Chemical Engineering, North Carolina State University), and Michael Prince (Professor of Chemical Engineering, Bucknell University).

NETI has been hosted every year for the past 24 years and has trained 1312 participants from 244 different institutions. The objectives of NETI-1 is to give the participants a hands-on training in the elements of effective teaching, which include course planning, lecturing, active learning, assessment of learning, and dealing with a variety of problems that are typical to academic careers. The workshop also provides new faculty with tips that help them get their careers to a good start, while equipping experienced faculty with instructional materials and methods that can used in in faculty development and new faculty mentoring programs on their respective campuses.

### 4.4 The ExCEEd Model

First developed for training a constantly rotating faculty at the West Point Military Academy, the Excellence in Civil Engineering Education (ExCEEd) model was adopted by the ASCE in 1999. ASCE has since trained scores of young faculty in Civil Engineering in this model through their annual workshops. This model is explained in great detail in Estes et. al (2005)[12], and several graduates of this program have recounted their experiences, using this model, across various civil engineering disciplines. For example Rutherford and Palomino (2014)[13] describe their experience of applying the model across the entire department at the University of Tennessee, Knoxville. Mladenov et. al., (2013)[14], describe the efforts of three ExCEEd graduates to apply the lessons from the workshop to each of their institutions in an introductory environmental engineering course.

What sets the ExCEEd model aside is the practicality of the training. By the time graduate students become faculty and begin to identify their shortcomings, they have few options in sitting in a class to be taught so that they could learn back from experienced professors. ExCEEd provides this missing link. Participants are given the opportunity to once again sit as students in demonstration classes taught by experienced professors who bring the ExCEEd model to life. These "students" are given the opportunity to assess their learning experience feedback to the instructors. They are then given the opportunity to develop and teach three different classes to be assessed by peers and mentors. The constructive feedback and video playbacks provide valuable insights to the students. Teaching a number of classes with feedback throughout the week with new lessons and sitting in the demonstration classes build the participants and position them to derive much benefit from the program.

Moreover, the ExCEEd model places student learning at its core. By acknowledging that each student has a different learning style[15], sensory or intuitive, visual or verbal, inductive or deductive, active or reflective, and sequential or global, the model encourages instructors to develop their lessons to address various learning styles.

## 5. ExCEEd application and reflections

We have each applied different aspects of the ExCEEd teaching model in the various classes that we teach, since each of us graduated form the program. For example Table 1 breaks down the ExCEEd instruction model described in Estes et. al., (2005)[12], into what each author implemented in their classrooms (with some examples).

**Table 1. Implementing the ASCE ExCEEd model**

| Model activity | Kulkarni (Environmental) | Tefe (Transportation) |
|---|---|---|
| | Structured Organization | |
| Learning Objectives | Yes | Yes |
| Learning styles | Assessed in the beginning of the class; activities attempt to address various learning styles | Performed different activities to meet the different learning styles |
| | Engaging presentation | |
| Clear written and verbal communication | Board notes, use of visuals in PowerPoint | Board notes supported by visuals in PowerPoint |
| High degree of contact with students | Movement in the classroom, inviting students to the board | Movement across the classroom and occasionally inviting students to the board |
| Physical models and demonstrations | A combination of props to demonstrate activities in the classroom, and walking students over to the lab for a quick demonstration as needed. | Used props to demonstrate activities in class |
| Frequent assessment of student learning | Questions, individual and group activities, inviting students to the board | Questioning, Individual and group activities, inviting students to the board |
| Appropriate use of technology | Blackboard, PowerPoint, limited lecture capture, videos. | Blackboard, PowerPoint and videos |

In addition to the specifics provided in Table 1 above, the enthusiasm and positive rapport with students is established by activities such as playing their favorite music as they walk into the classroom, relating classroom concepts to ongoing activities in the university and elsewhere in the world.

Reflections: Some specific examples of applying the ExCEEd model in the Kulkarni's introductory environmental engineering classroom have included activities ranging from using sketches, videos, and PowerPoints for visual learners, to discussions and service-learning based projects for global learners. Figure 1 summarizes the results of twenty-four students surveyed in fall 2013 for their preference in activities performed in the course by ranking activities from 1 to 10. As seen in Figure 1, students have a large preference for visual presentation of information (56.25% PowerPoint supported lectures, and concept sketches (40%). They also appreciated field trips (50%) and quizzes (40%). Discussions (33.33%) and service-learning projects (26%) also seemed to appeal to a good percentage of the student body.

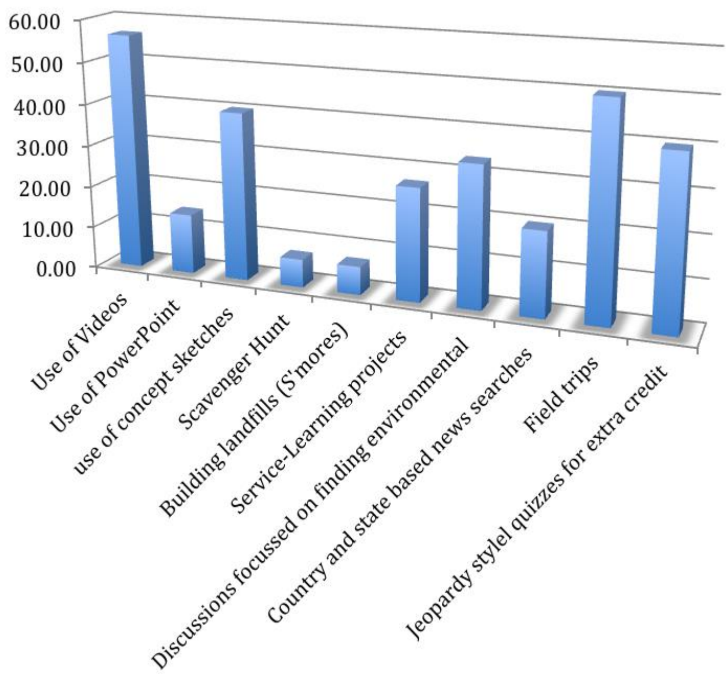


**Figure 1. Student preferences for activities in an introductory environmental class.**

Also Tefe realized a 1.02 jump in his student evaluation after implementing the ExCEEd model the semester immediately following the workshop. A list of specific activities that he incorporated into his classes to warrant this remarkable lift in assessment are presented below. The next step is to make quantitative assessment of the effects of these impacts on student outcomes, and this will be done in subsequent semesters:

- Wrote clear instructional objectives at appropriate cognitive levels in accordance with Bloom's Taxonomy

- Gave practical examples, relating theory to practice and also gave the students practice oriented home works and exercises,
- Adopted active learning techniques like one minute paper and students generating test questions from lecture materials
- Developed short 3-4 minute group activities in class to keep students keep engaged. He particularly allowed students to attempt solving problems together before giving them the solutions
- Assessed learning outcomes through quizzes, homeworks and student feedbacks.
- Sometimes letting students write muddiest points or the most important points in the lessons and the professor also performing self-assessment to identify areas for improvement.
- Reduced lecture notes to concise workable board notes, and also integrated the use of blackboard and visuals
- Developed positive rapport with the students, showed more enthusiasm in the classroom, and made classes more interactive.

## 6. Conclusions

Most academic careers exist in small universities and colleges, where faculty members are expected to be effective teachers and academic citizens, in addition to being competent in research. Of these expectations, however, teaching is the responsibility that demands most immediate attention and consumes most energy from new faculty, because the new faculty is expected to come in as an effective teacher. Unfortunately the research component of doctoral education is often emphasized at the expense of the development of broader skills that are needed for success in academic careers. So new faculty hires are coming in ill prepared for teaching, while most institutions are also increasing the emphasis placed on teaching quality. Many institutions also expect their faculty to adopt new pedagogies that address the different learning styles of their students.

Apart from localized faculty development programs that exist in many institutions including the SUCCEED faculty development program, a number of training workshops also exist that are organized every year and are open to new engineering faculty from across the nation, especially new faculty. The notable among these programs include ASCE ExCEEd teaching workshop, Project Catalyst at Bucknell University and the National Effective Teaching Institutes (NETI)

These programs provide valuable training that are designed to reduce the learning curve for new engineering professors in becoming effective teachers, and thus helping provide a solid base for the training of future engineering professionals. Limited results from Norwich in particular show that the ExCEEd model products are popular among the students and could have significant impacts on student learning

## References


1. R. Brent, R.M. Felder. 2003. A model for engineering faculty development. *Int. J. Engineering Ed*. Vol. 19, No. 2, pp. 234-240,
2. K.A. Adams. 2002. What colleges and universities want in new faculty. Preparing Future Faculty Occasional Paper, Number 7. Washington, DC: Association of American Colleges and Universities.
3. S. Campbell, A.K. Fuller, D. Patrick. 2005. Looking beyond research in doctoral education. Frontiers in Ecology.3:153–160.
4. R. Boice. 2000. Advice for New Faculty Members, Allyn & Bacon, Needham Heights, MA.
5. A.L. Deneef. 2002. The preparing future faculty program :What difference does it make , *Association of American Colleges and Universities Series of Occasional Papers*
6. V.A. Benassi, and W. Buskist. 2012. Preparing the new professoriate to teach. In W. Buskist & V. A. Benassi (Eds.), *Effective college and university teaching: Strategies and tactics for the new professoriate*. (pp. 1-8). Thousand Oaks, CA: Sage.
7. L.F. Siedel, V.A. Benassi and H.J. Richards. 1999. College teaching as a professional field of study: The New Hampshire model. Unpublished manuscript.
8. A.S. Pruitt-Logan and J.G. Gaff. 2004. Preparing future faculty: changing the culture of doctoral education. In: Wulff, DH and Austin AE (Eds). Paths to the professoriate: strategies for enriching the preparation of future faculty. San Francisco, CA: Jossey-Bass.
9. W. Buskist, R. Tears, S.F. Davis. and K.M. Rodrigue. 2002. The teaching of psychology course: Prevalence and content. *Teaching of Psychology, 29,* 140–142.
10. R. Brent, R.M. Felder, D. Hirt, Switzer and S.A. Holzer. 1999. A model program for promoting effective teaching in colleges of engineering, Proceedings, 1999 Annual ASEE Meeting, ASEE, Washington.
11. D.C. Prince, E.J. Hyde, F.J. Mastascusa, M. Vigeant, M. Hanyak. 2001. Project Catalyst: Successes and Frustrations of Introducing Systemic Change to Engineering Education, Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.
12. A.C. Estes, R. W. Welch, and S. J. Ressler, Teaching Lessons Learned, Journal of Professional Issues in Engineering Education and Practice, ASCE, October 2005, pp. 218- 222, (2005)
13. J. Q. Rutherford, and A. M. Palomino, Departmental Implementation of ASCE’s ExCEEd Teaching Principles, 2014 ASEE Southeast Section Conference, American Society of Engineering Education, (2014). Available at http://se.asee.org/proceedings/ASEE2014/Papers2014/84.pdf.
14. N. Mladenov, T. Kulkarni, and M. London, 2014, Use of In-Class Demonstrations and Activities to Convey Fundamentals of Environmental Engineering to Undergraduate Students, 121$^{st}$ American Society of Engineering Education (ASEE) Annual Conference and Exposition, June 15-18, 2014
15. R. M. Felder, Matters of Style, ASEE Prism, 6(4), 18-23, December 1996.

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# Joint-Venture Modules: A Technique in Teaching Students How to Recognize and Analyze Ethical Scenarios

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## Abstract

Preparing engineering students on how to recognize and resolve ethical circumstances can increase their awareness of and ability to navigate ethical dilemmas they will encounter in their professions. Many engineering programs do not have a systematic incorporation of ethics, leaving students without a clear understanding of the significance of ethics in everyday engineering decisions. The aim of this project is to develop a system of ethics modules that can be easily integrated into engineering courses. A preliminary study found that a majority of students preferred a joint-venture approach over other methods of teaching ethics. The joint-venture module incorporates an ethics guest lecturer who exposes students to a variety of tools to better comprehend ethical responsibilities. Customized joint-venture modules were then piloted in biomedical engineering courses at varying class levels. Professors involved indicated that the ethics analyses were easy to incorporate into their curriculum without distracting from the engineering content, and 90.5% of the participating students agreed that the ethics guest lecture was helpful in understanding the material.

## Keywords

Ethics, engineering, biomedical, undergraduate

## Introduction

Engineers design and manufacture products and processes that are used to improve the lives of other people. In the professional setting, decisions are often made that can compromise the safety and effectiveness of a design due to cost reduction or increasing the ease of manufacturing. Preparing students to encounter these scenarios can help promote ethical reasoning, and may help reduce ethical issues that arise in the work force. Current studies indicate that engineering curricula do not emphasize the exposure of students to engineering ethics, and as a result, professional ethics is not sufficiently covered in these engineering programs.[1, 2] Recent ABET reports show that only a few of the biomedical engineering (BME) courses offered in most university level curricula provide any exposure to engineering ethics in class.[3] Students have also reported that they encounter little to no ethical content as part of their undergraduate studies. Across the curriculum in many engineering schools, there is a lack of ethics incorporated into technical courses, which may leave students unaware of the impact of everyday decisions they will make in their professions. These decisions may influence the design of a product, which may in turn have an effect on the general public.

In 1999, a study determined that nearly 70% of ABET-accredited institutions did not have an ethics-related course requirement for students in engineering programs.[4] However, even in the schools that did have an ethical requirement, there was a lack of courses focused explicitly on engineering ethics. More recently, in 2007, research was conducted across three medical universities to determine whether new graduate engineering students had a sufficient background in ethics. Results from the study indicated that student understanding of ethical responsibilities had a low baseline, with a mean score of 59.5%.[5] In order to create more ethically conscious students, many schools have since added an ethics component to their engineering major requirements, usually in the form of a single ethics class.[6] However, experts at Stanford largely agree that taking a single ethics course will not make a student a more ethically aware individual.[7]

Previous studies have shown that by simply introducing ethical discussion into class, students are encouraged to engage in ethical dialogue, clarify their own values and commitments, and recognize potential ethical issues.[6] While some schools add an ethics course requirement, others may supplement engineering course syllabi with ethics components.[6] Using this method, the engineering professor gives a lecture on ethics using case studies as a means of engaging students in discussion.

This project is focused on creating a user-friendly, versatile, and time efficient method for incorporating ethics modules into pre-existing engineering courses that will allow students to identify and navigate ethical scenarios in the context of the technical content of the course. Each ethics module is based on case studies relevant to the engineering subject matter, which encourages students to become more engaged in the process of recognizing and understanding ethics issues.[8] It is also important to stress that ethics is not a separate component from engineering, but intricately related to the subject. Our belief is that an interactive discussion with an ethics professional, along with engaging case studies and analytical assignments, will allow the students to become more aware of ethics in professional life, as well as how to handle them when they arise.[9] We developed and integrated ethics modules into three biomedical engineering courses at Worcester Polytechnic Institute to assess student interest in the joint-venture method.

## Previous Study (2013)

In a previous study conducted at Worcester Polytechnic Institute in 2013, a project team investigated the lack of resources for ethical education in the biomedical engineering curriculum.[10] They embarked on the task of creating various resources which biomedical engineering faculty could use to incorporate some form of ethics in their classes. Two senior-level classes were utilized in their study, in which case studies related to course content were assigned to students. In one class, two methods of incorporating ethics (a point-counterpoint assignment and a six-step case analysis assignment) were given, and in the other class, only one method was utilized (point-counterpoint). Course credit was given to participating students as a means of motivation, and there was a high response rate overall, ranging from 92% to 94%.[10]

Results from the study indicated that the majority of students enjoyed the point-counterpoint assignment, as it allowed students to weigh the pros and cons of a scenario, allowing for multiple perspectives. The analysis assignment was also popular with the students, as they felt that it helped to organize their ideas and keep track of ethical issues within a case study. From a survey, 79% of students indicated they would keep a copy of the six-step analytical method for future use.[10] While both methods of teaching ethics were well received by students, some students reported a preference for the point-counterpoint assignment, as it was less time consuming and easier to do.

Feedback from the engineering professors showed that they felt the ethics assignments were useful. One professor stated that preparation for the point-counterpoint assignment took one hour to complete, and the six-step analysis assignment took two hours to complete. The project team for this first study developed a handbook with instructions on implementing a point-counterpoint assignment and an analysis assignment, along with other helpful tips for biomedical engineering professors who wish to incorporate more ethics into their curriculum.

## Preliminary Study Methodology

For a preliminary study, initial data were collected using a sophomore-level biomechanics course. The study was conducted to gather feedback from students regarding the various teaching methods they were exposed throughout the course. Data from the students allowed us to gather a sense of how comfortable the students were with ethical thinking, which method of teaching ethics they preferred, and which method they felt they learned the most from.

Three methods of teaching ethics were evaluated tested and feedback obtained from the students as well as the engineering professor. In the first method, the engineering professor assigned a case study and led an in-class discussion regarding the ethical points in the reading. The professor had no formal training in teaching ethics, and reported that only a few students engaged in discussion. The second method of teaching ethics used a different case study and a point-counterpoint assignment, much like the previous study conducted in 2013 at WPI.[10]

After reading the case study, the students were required to write two paragraphs relaying an argument for and against a point from the reading. The purpose of a point-counterpoint assignment is to engage students in thinking alternatively and emphasizing that there are multiple aspects in a single situation. It is important for students to understand that behind professional decisions are valid reasons, and students will need to reflect on the reasons for their decisions when entering the workforce. Credit was given to students if they attempted the assignment and supported their answers. The third and final method of teaching ethics was a joint-venture approach, where an ethics professor with experience in leading discussions in ethics came in as a guest lecturer regarding a different case study.

At the end of the course, a survey was given to the students regarding which method the students preferred and learned the most from, as well as additional information the students may have had to offer.

## Pilot Study Methodology

Based on analysis of data from literature, the previous study in 2013, and the preliminary study with the sophomore-level biomechanics course, we proposed that the best way to easily incorporate ethics into an engineering curriculum was to use an across-the-curriculum, joint-venture approach with case studies. Ethics modules were developed which incorporated these elements, and implemented into three separate biomedical engineering courses at varying levels (freshman, sophomore, and senior). The method of teaching ethics was similar in all the courses, using case studies related to engineering content, a 50 minute guest lecture from an ethics professor, and two assignments to reinforce ethical knowledge. The case studies also varied in difficulty level to accommodate for different course levels. For example, the freshman class was given a fairly straight-forward case study, while the senior class had a longer, more in-depth case study.

After assigning the case study for reading, the first assignment in the ethics module was a point-counterpoint assignment which included the basics on how to form point-counterpoint arguments. The assignment was structured to be approximately two paragraphs in length, where the student would first argue his or her own view on the case study, and then defend the view opposing his or her own. It was expected that the point-counterpoint assignment would aid students in understanding issues at hand more comprehensively.[11]

After the point-counterpoint assignment was completed and handed in, an ethics professor lectured the class on general ethical theories and the importance of ethics, as well as material required for thoroughly understanding the case study assigned prior to the lecture. A post-lecture heuristic assignment was then given to students, similar to the six-step case analysis assignment from the previous year's study. The heuristics assignment asked the students to identify various ethical aspects in the case study and provide reasoning for their opinions on how to handle the situations presented in class. It would step the students through how to handle an ethical situation and coming to an end conclusion.

A student questionnaire after the heuristics assignment served to evaluate student opinion on the ethics module and whether they found it beneficial. All the professors participating in our study were interviewed to gather input regarding the content and application of the ethics modules. Engineering professors were asked to voice their views on the overall module effectiveness, ease of use, likeliness of future use, and other such opinions. Ethics professors were asked to provide thoughts on module improvement, effectiveness, and general comments about the time and effort required to prepare for the ethics lecture, and whether they would like to participate in future modules.

## Preliminary Study Results

Three methods of teaching ethics were incorporated into a sophomore-level biomechanics class, and students were asked to indicate which method they preferred in an end-of-course survey. From Figure 1, it can be seen that a majority of students preferred the ethics professor's guest lecture over the other methods of teaching ethics.

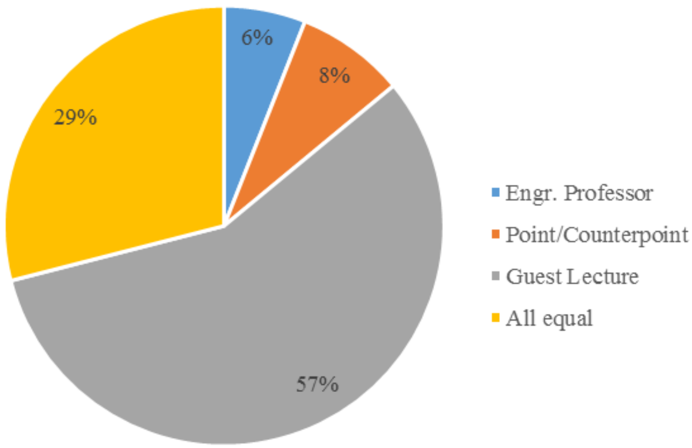


Fig. 1: Student preference of the three ways of teaching ethics from the preliminary study, with n=60 of 85 students in a sophomore-level biomechanics class.

When asked which method they felt they learned the most from, students also indicated that the ethics professor provided the most usable ethical content, as seen in Figure 2.

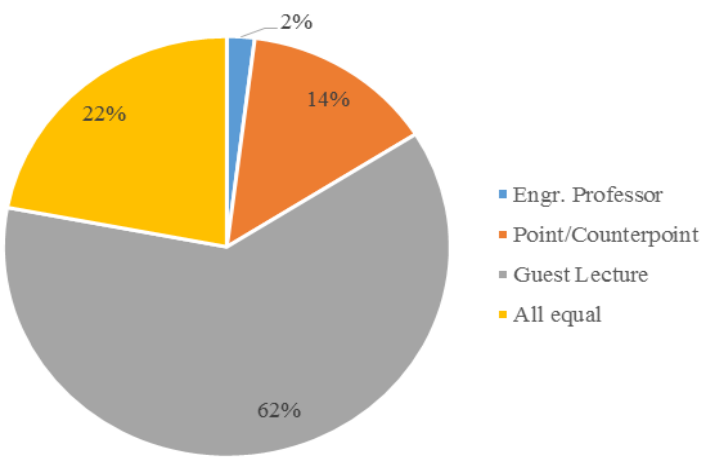


Fig. 2: Perceived student learning from the three ways of teaching ethics from the pilot study with n=60 of 85 students in a sophomore-level biomechanics class.

When interviewed, the engineering professor also stated that he favored the guest lecture, as he felt that the ethics professors was able to discuss the ethical theories and implications in greater detail due to a formal training in ethics. It was found in the survey that 80% of the students claimed to have learned something new from the guest lecture, and would like to see a similar ethics approach in the future. Of the students in the initial study, 75% would also consider taking a full BME ethics course in place of an across-the-curriculum study.

**Pilot Study Results**

From the collected research in literature, the previous year's study at WPI, and the preliminary study conducted by our group, an ethics module with case studies was developed centered around an ethics lecture from an expert in the field. The modules were incorporated into each of three courses ranging from freshman- to senior-level. The courses had small to large student populations, and the modules constituted various proportions of the final course grade, shown in Table 1.

Table 1: Expanded study with course level, number of students, and participating students

| Course Title | Course Level | Number Of Students | % Of Course | Participating Students |
|---|---|---|---|---|
| Introduction to Biomedical Engineering | Freshman | 81 | Bonus points | 90.1% |
| Biomedical Signals, Instruments, and Measurements | Sophomore | 94 | 3% | 75.5% |
| Innovation in Biomedical Engineering Design | Senior | 28 | 5% | 93% |

Overall, the participating students in all three classes found the guest lectures insightful in understanding the case study assignment. Upon completion of the module, most students indicated that they were more confident in facing ethical situations and would know how to handle them, as opposed to the beginning of the class. Feedback showed that the majority of participating students would like to continue seeing similar modules implemented into the BME curriculum. Table 2 shows the complete list of module opinion questions that were asked to the students upon completion of the module, as well as the overall student responses.

Table 2: Average student responses of all three courses to effectiveness of expanded study

| Question # | Question | Yes |
|---|---|---|
| **1** | Did you find the ethics guest lecture helpful in understanding the assigned case study? | 90.5% |
| **2** | Did you learn anything new regarding how to analyze ethical situations? | 82.4% |
| **3** | If encountered with an ethical situation in the work force, would you know how to identify, analyze, and handle it? | 90.6% |
| **4** | Are you any more confident in facing an ethical situation now than you were in the beginning of the term? | 81.7% |
| **5** | Did the ethics module distract from the technical core course work too much? | 10.6% |
| **6** | Would you consider taking a full (1/3 credit) BME ethics course? | 70.6% |
| **7** | Would you want BME courses to incorporate a similar ethics module in the | 84.6% |

| | | |
|---|---|---|
| | future? | |

After the ethics modules were completed, we interviewed the engineering professors and ethics guest lecturers to gather input on their opinion of using the module. The engineering professors all stated that the ethics module was easy to incorporate into their class schedule, and the content was not distracting from the main engineering material. Given the chance, they would be willing to implement the module again into future courses. However, one engineering professor thought that the guest lecture was a bit too in-depth in discussion of ethical theories, and did not explain how the ethical theories applied to the different aspects of the case study thoroughly enough, making the analysis assignment a bit challenging for the students. The ethics professors indicated that the ethics module was a significant step in bringing more ethics into an engineering curriculum, but a more in-depth component needs to be established in the future. The guest lectures were not difficult to prepare, and the ethics professors received inquiries on further pursuit of ethical knowledge from many participating students after the guest lecture.

## Discussion

Overall, the joint-venture approach showed to be both successful and popular in exposing students to ethical material. A majority of students in each class indicated that they felt they could better identify, analyze, and handle ethical situations experienced in the workforce, and approximately 85% stated that they would like to see more ethics modules implemented in future engineering courses. Student opinion indicates that we were successful in both exposing them to situations with ethical components and helping to improve their ability to handle these situations. The developed module was not too distracting from normal coursework, as 89% of the students stated. A majority of the students, 70%, also showed that they would consider taking a full ethics course. In addition, interviews conducted with both the engineering and ethics professors support that the amount of time required for both parties in coordinating guest lectures and presenting material was easy to manage.

In biomedical engineering, there are various and distinct components of ethical thinking to take into consideration. A comprehensive ethics curricula would need to cover the fundamentals of ethics, research ethics, professional ethics (including the ethics that govern an engineer's behavior and the ethics governing a medical professional's actions), and social ethics.[12] In a broad sense, there are three primary strategies of incorporating ethics into a curriculum: the across-the-curriculum model, stand-alone courses, and the joint-venture approach.[13] The joint-venture approach takes into account that engineering faculty may not have enough background to teach ethics well, and ethics professors may not have enough engineering experience to relate ethics with engineering. Guest lectures break the monotony of a class, thus keeping students engaged and interested.[6] The diverse specializations of various faculty members allows for many fields of expertise to be covered, incorporating both engineering material and ethics material.

Throughout implementations of this study as well as the study conducted in 2013, case studies were utilized. Case studies require the students to read about a situation, think about the different aspects and options, and engage students in the issue.[14] Engineering professors generally do not feel that they have expertise in teaching ethical concepts and thinking, and may not feel entirely comfortable with leading a discussion in ethics. Having an expert in ethics come in to lead a discussion in ethics not only allows for the exposure of students to ethical content, but also for the engineering professor to gain some better understanding of how to incorporate ethics into the curriculum.[15] Students may also feel more at ease with an ethics professor teaching ethics, since there is a sense of perceived expertise. The confidence level in the professor and the perceived credibility of what the professor says increases for the students.[16]

It has been suggested that an integral part of learning ethics lies within understanding the various components and paths of an issue.[17] In our implementation, after the guest lecture, the students were assigned a more in-depth assignment to identify the ethical points of conflict, interested parties, the possible courses of actions and their respective consequences, and the moral obligations of the engineer in question to ensure that the students examined different components in the case study.

The ethics professors who guest-lectured in the engineering courses all agreed that they had enough time and resources to prepare an ethics lecture for the respective classes, even though they were not specifically compensated for teaching the modules over and above their normal teaching load. The ethics module, in their opinion, is a good start to exposing students to more ethics and broadening their mindset. However, the ethics professors also reported that in order to fully educate the students on ethical values, there needs to be a more in depth component to their education.

## Future Recommendations

While our developed ethics modules attempt to meet students' needs for proper ethics training, there is still plenty of work to be done towards implementing a formal, more complete system. The modules introduce the topic of ethics in individual engineering classes, and give the students a few tools to help identify and navigate ethical situations. However, the modules for the scope of this project were tailored specifically for each course, and do not adequately address the larger issue of incorporating ethics comprehensively into an entire engineering curriculum. Work needs to be done on how to relate the ethics modules within all the classes without becoming overly repetitious and monotonous for the students. Different class levels should have different levels of complexity in presented ethics material. By the time a student graduates, he or she should have a complete ethics education to supplement their engineering curriculum.

For the purpose of this project, we acted as an intermediary between the BME department and ethics professors who volunteered to guest lecture. A new system needs to be established where a more direct means of communication is available for the joint-venture lectures. This will prevent communication errors and delays in messages. Also, the professors will be able to become better acquainted and can make the lessons more relevant. While our project was generally received positively by the students and professors, a more long term study may be necessary to observe what they think of the long term exposure in each class.

## Conclusion

There is a lack of ethics training incorporated into engineering courses today, which may leave students unaware of the importance of the ethical dimensions of day-to-day decisions made in their professions. A method using ethical modules was developed to increase ethical exposure and teach students how to identify and navigate ethical situations in the context of their technical coursework. Our study incorporated ethics modules into three classes, with overall positive results. Students indicated that they were more open to ethics-based lessons, and professors in both the biomedical engineering and philosophy departments agreed that the module was effective in exposing students to potential ethical situations they may experience in a professional setting.

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## References

1 Herkert, Joseph, “Engineering Ethics Education in the USA: Content, Pedagogy and Curriculum”, European Journal of Engineering Education, 2000, 25(4):303-13.
2 Zandvoort, Henk, Ibo Van de Poel, and Michiel Brumsen, “Ethics in the engineering curricula: Topics, trends and challenges for the future”, European Journal of Engineering Education, 2000, 25(4):291-302.
3 ABET. Criteria for Accrediting Engineering Programs 2013-2014.
4 Stephan, Karl, “A survey of ethics-related instruction in US engineering programs”, Journal of Engineering Education, 1999, 88(4):459-464.
5 Heitman, Elizabeth, Cara Olsen, Lida Anestidou, and Ruth Bulger, “New Graduate Students’ Baseline Knowledge of the Responsible Conduct of Research”, Academic Medicine, 2007, 82(9):838-45.
6 Lynch, William, “Teaching Engineering Ethics in the United States”, IEEE Technology and Society Magazine, 1997, 16:27-36.
7 Teaching with Case Studies. Speaking of Teaching. Winter, 1994, 5(2).
8 Plemmons, Dena, and Michael Kalichman, “Discussion Tools. Resources for Research Ethics Education”, http://research-ethics.net/discussion-tools/current-events. 2008.
9 Mance, Ksenija, “Engineering Ethics Teaching”, Engineering Review, 2007, 27(2):83-91.
10 Cantwell, Meghan, Peter Lam, Kevin Reyer, and Richard Matthew Rafferty, “Improving Ethics Education in Engineering”, Interdisciplinary Qualifying Project at Worcester Polytechnic Institute, 2013-2014.
11 Brunner, Judy, I Don’t Get It!: Helping Students Understand what They Read, R&L Education, 2011.
12 Monzon, Jorge, “Teaching Ethical Issues in Biomedical Engineering”, International Journal of Engineering Education, 1999, 15(4):276-281.
13 Li, Jessica, and Shengli Fu, “A systematic approach to engineering ethics education”, Science and Engineering Ethics, 2012, 18(2):339-349.
14 Pimple, Kenneth, “Using case studies in teaching research ethics”, Indiana University, 2007.
15 Zandvoort, Henk, Gillian Van Hasselt, and Jonathan Bonnet, “A joint venture model of teaching required courses in ‘ethics and engineering’ to engineering students”, European Journal of Engineering Education, 2008, 33(2):187–195.
16 Trafimow, David, and Janet Sniezek, “Perceived expertise and its effect on confidence”, Organizational Behavior and Human Decision Processes, 1994, 57(2): 290-302.
17 Bebeau, Muriel, Kenneth Pimple, Karen Muskavitch, Sandra Borden, and David Smith, “Moral Reasoning in Scientific Research”, Cases for Teaching and Assessment, Bloomington, IN: Poynton Center for the Study of Ethics and Assessment, 1995, 7(3):112-143.

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# External Collaborator/Mentor Requirement for Senior Capstone Engineering Design Courses

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**Abstract**

To meet the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (EAC of ABET) curriculum requirement of a "major design experience", Civil Engineering Students at Wentworth Institute of Technology are required to successfully complete a Civil Engineering Capstone Design Course during the final semester (summer) of their senior year. In groups of four to six students, students develop, implement, and present a comprehensive, intra-discipline civil engineer design project. In the summer of 2014, the Faculty of the Civil Engineering Department at Wentworth Institute of Technology instituted a new requirement for the students enrolled in this Capstone Design Course. Each student group was required to identify and obtain the services of at least one External Collaborator (Mentor). The mentor's role was to act as a valuable resource throughout the semester for the students providing design guidance, regulation interpretation, actual project details, key contacts, and other relevant information. In addition to guidance throughout the semester, the external collaborator was to participate in an onsite mid-semester design review and attend/assess an end of semester formal presentation by the students of their design. All student design groups were successful in obtaining the assistance of at least one professional to act as a mentor, with many groups having several mentors with expertise in various sub-disciplines of civil engineering.

Some of the many benefits achieved by this new course requirement included mid-semester design review, professional networking, external assessment, showcasing of the program, and student employment possibilities. This paper addresses the successes of this new requirement in a capstone design course as well as the lessons learned from the first semester trial of the requirement.

**Background**

Wentworth Institute of Technology had a long standing history of delivering a highly regarded Civil Engineering Technology program. Early in 2010, the Administration of the Institute and the Faculty of the Department of Civil Engineering and Technology began the dialog related to developing a Civil Engineering program at Wentworth Institute of Technology. Following the requirements of Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (EAC of ABET) "Criteria For Accrediting Engineering Programs" and the recommendations of the American Society of

Civil Engineers (ASCE) report "Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future", a new Civil Engineering program was developed. After much debate and effort, in the fall of 2011 Wentworth Institute of Technology accepted its first class into a newly created Civil Engineering Program. This class consisted of both freshman applicants and sophomore transfer students from the Civil Engineering Technology Program.

The mission of the Civil Engineering (BSCE) program at Wentworth Institute of Technology is to "provide a high quality undergraduate education that prepares graduates with the appropriate knowledge, skills, and attitudes to successfully begin a career in the civil engineering profession and continue to grow professionally and personally throughout their career". The mission of the program is accomplished through the program curriculum which include courses with traditional lecture course, lecture/laboratory courses, design project courses, and two mandatory Co-op semesters.

**Civil Capstone Design - Course structure, scope and schedule**

Civil Capstone Design (CIVE 650) is the program's capstone design course to meet the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (EAC of ABET) curriculum requirement of a "major design experience". Senior status is required to enroll in CIVE 650 and the course is scheduled in the senior's final summer semester. In this course, students utilize acquired knowledge and developed skills from the previous program and other coursework to create civil designs and solve practical problems encountered during the design process. While developing their designs, students work cooperatively in a four to six member intra-discipline design team, demonstrate oral and written communication skills and apply independent research skills while interpreting design criteria and formulating appropriate design solutions. The open-ended design/build projects must include a design component in each of the following civil engineering sub-disciplines:

- Geotechnical Engineering
- Structural Engineering
- Civil/Site Engineering
- Environmental Engineering

Additional topics covered include value engineering, cost, safety, construction feasibility, construction scheduling, engineering ethics, and a wide range of engineering design elements.

The course format is one – one hour lecture and two three-hour studio/labs per week.  The total credits assigned to this course are four. Multiple faculty advisors each with specific expertise in the above mentions disciplines are assigned to the course. The faculty advisors are available to advise the students during the lecture, studio/lab, and outside of the scheduled class times.

The beginning of a typical lecture period is used to review expectations for the upcoming week and the requirements for the upcoming deliverables (submittal requirements, deadlines, presentations, and the final report).  Following the course update, a topic related to an engineering design project is discussed by one of the faculty advisors. See Figure 2 for a typical lecture schedule. Sufficient time is allowed in each lecture period to answer general questions the students may have.

The studio/lab is held in an oversized open space studio with individual space assigned to each design group. The individual space consist of a large working surface, bulletin boards, and secure storage. The two three-hour studio / lab sessions per week give students time to work on their designs and allow the faculty advisors to meet twice per week which each group individually. During these meetings the work completed since the last meeting is reviewed, design schedules are updated, problems are addressed, and working needed to be completed for the next meeting is agreed upon.

The structure of the Civil Engineering Capstone course was adapted from the previously taught Civil Engineering Technology Capstone Design course.  One of the many changes to the technology version of the course that was incorporated into the new class was the requirement for the students enrolled in this Capstone Design Course to identify and obtain the services of at least one External Collaborator (Mentor). The mentor’s role was to act as a resource throughout the semester for the students providing design guidance, regulation interpretation, actual project details, key contacts, and other relevant information. In addition to guidance throughout the semester, the external collaborator participated in an onsite mid-semester design review and attend/assessed an end of semester formal presentation by the students of their design. Table 1 list the project teams, a description of the student projects, and the Mentor’s associated with each project.

| Table 1 - 2014 Civil Capstone Design Projects | | | |
|---|---|---|---|
| **Project Title** | **Students/Lead Area** | **Description** | **External Collaborators** |
| Brewery Design, Westport, CT | James Clough - Structural<br>Thomas Julian -Geotechnical<br>Brian Mangiamele -Site/Civil<br>Branden Roberts -Water Treatment<br>Kevin Russ - Environmental<br>Zaharadeen Sadiq -Structural/Site/Civil | The proposed project is to construct a brewery on a selected site in Westport, CT. To be considered in design are the structural elements of the building, site layout/drainage, environmental impact mitigation, geotechnical analysis, as well as water and wastewater treatment for the brewery. Some issues specific to the brewery will be: high biochemical oxygen demand of effluent, heavy brewing tanks, and parking for tour groups. | Tom Bowker-Cardno ATC<br>Peter Salvatore-Boston Water and Sewer Commission |
| Morses Pond Well Field & Treatment Facility, Wellesley MA | Michael Buonincontra - Structural<br>Dana Judge - Geotechnical<br>Erin Cahill - Site/Civil<br>Tyler Schmidt - Site/Civil<br>Jeffrey Leggett - Hydraulic<br>Saajan Patel - Environmental | The project focus is potable water infrastructure. The project involves the installation of public wells on a site next to a public pond and the construction of a pump station and treatment plant. The Town of Wellesley expects this facility to be rehabilitated to a capacity of 3 MGD year-round. | Blake Lukis-Director of Water and Sewer in Framingham, MA |
| Stony Brook Residential Development Project, Jamaica Plain, MA | Abel Arguedas - Structural<br>Juan Morales - Geotechnical<br>Wilfredo Reyes - Water/Civil<br>Viana Reyes - Water/Civil<br>Steven Glover - Environmental<br>Daniel Rowett - Environmental/Geotechnical | The Stony Brook Residential Development Project was started as an Architectural Design project from the Spring Semester. The project was a two phase redevelopment project. The group will use the architectural rendering from the previous semester and develop the structural design of a four story mixed use building, a parking lot in compliance with local zoning regulations, storm water/water/sewer designs and an accompanied green space. The building will be 245 ft. by 75 ft. in size and the green space area will be 125 ft. by 245 ft. Phase 2 of the architects' project which consist of the design for a second residential building and the restoration of Stony Brook Canal will be considered in the laying out of the site but no design work will be completed in Phase 1. | Brent Shannon-McNamara/Salvia Inc.<br>Bryan Mah-Wentworth Institute of Technology |
| Hotel, Parking Garage, and Green Roof, 1271 & 1282 Bolyston St., Boston, MA | Brian Barker - Civil<br>Brendon Cioto - Geotechnical<br>Nicholas Dempsey - Structural<br>Cody Gibb - Structural<br>Daniel Jameson - Environmental<br>Christopher Pyman - Environmental<br>Abele Komguep - Geotechnical | The proposed project is for the redevelopment of two site in the Fenway Park area along Boylston Street. The current Howard Johnsons at 1271 Boylston Street would be demolished and a new multistory hotel would be constructed in its place. Across the street, at the 1282 parcel, the existing parking lot would be expanded to a multilevel below ground parking structure. At street level, there would be retail and restaurant space. The 1282 Roof Top would be made into a green space, accessible to the public and hotel guests across the street. The Hotel at 1271 Boylston and the Green Roof at 1282 Boylston would be connected be an elegant walking bridge spanning Boylston street. | Kevin Wong-Haley and Aldrich<br>Lee Vanzler- Haley and Aldrich<br>Michelle Jose-HNTB<br>Christopher Brennan-Walker Parking<br>Tom Fennick-McPhail Associates<br>Jonathan Patch-McPhail Associates<br>Tim Lombard-Leggat McCall Properties<br>Eric Kramer-CB&I<br>Linda Gardiner-CB&I<br>Paul Greco-Weston & Sampson Engineers<br>Shawn Cioto-Intercontinental Hotel |
| Mitchell River Bridge | Travis Archambault - Environmental<br>John Devlin - Structural (Steel) | The Massachusetts Department of Transportation has identified the Mitchell River Bridge of Chatham, MA as structurally deficient and as a result has placed it within | Mark Shamon<br>URS Corporation |

| | | | |
|---|---|---|---|
| Replacement, Chatham, MA | Freddie Falcone - Geotechnical<br>Nathan Goldman - Civil (Hydraulic)<br><br>Kristen Houatchanthara - Structural (Reinforced Concrete)<br><br>James McCarthy - Civil (Highway/Transportation) | the Accelerated Bridge Program. This proposed capstone design project is to design a replacement bridge to cross Bridge Street over the Mitchell River. It will be assumed that all components of the existing bridge will be demolished. The group will use their knowledge of the civil engineering sub-disciplines, structural; structural, geotechnical, transportation, hydraulics, and environmental in a comprehensive project by designing a new composite steel and concrete bridge superstructure supported by reinforced concrete piers/abutments and piles. Other design elements to be considered are roadway alignment, pavement design, drainage, and environmental impact. | Eric Johnston<br>CB&I |

## Successes

Many benefits were achieved by this new course requirement. A few of the more notable included:

1. Mid-semester Review - Each group conducted a mid-term review of their design project. The Mid-term Review was given to the faculty and the group's external collaborator(s)/mentor(s). The review was conducted outside of the design studio in a conference room with the options of teleconferencing if an external collaborator was not able to be on campus. Each team member was graded based on technical content and contribution, quality of presentation material, quality of presentation and how questions were addressed. These 4 categories are equally weighted in grading of the presentation. After the review, each group prepared an External Collaborator(s) Mid-term Report noting significant issues addressed, decisions made, and issues raised but not resolved at the Mid-term review. This report was forwarded to the External Collaborators and Faculty Members in attendance within one week of the meeting for review. The mid-semester review with the external mentor(s) provided the students with valuable design guidance, regulation interpretation, current industry practices, actual project details, project meeting experience (preparation, delivering project status in an organized fashion, and responding to questions), and key contacts.
2. Professional Networking – At the beginning of the semester, the majority of the external collaborator(s)/mentor(s) were known only by one or two of the student group's members and many were introduced for the first time to the faculty. After interacting with the students and the faculty for the semester, the mentors had become part of the student's as well as the faculty's professional network.
3. External Program Assessment – All of the external collaborator(s)/mentor(s) were involved in the mid-term review and many were present at the student's end of semester for formal presentation. At the completion of each of these presentation, the mentors completed an

External Collaboration Grading Rubric sheet. The results of the Rubric gave valuable insight into the student's performance and were incorporated into the Department's ABET Student Outcome assessment.

4. Showcasing of the Program – Many of the external collaborator(s)/mentor(s) were unaware of the new civil engineering at Wentworth Institute of Technology and many had never been or have not recently been on Wentworth's campus. By inviting the mentors to the campus for the student's presentations allowed them to see and learn about all the new and exciting things happening at Wentworth.
5. Student Employment Possibilities – Through the interactions the external collaborator(s) /mentor(s) had with the students throughout the semester, they became aware of the talents/capabilities of the individual students. Though only one student currently is known to have obtained employment from her/his advisor, the possibility for such employment is a benefit for the students.

**Failures**

Overall, the faculty involved in teaching CIVE 650 Civil Capstone Design did not identify any major drawbacks to requiring the student groups to identify and obtain the services of at least one External Collaborator (Mentor). As describe above and documented in the student's end of semester course evaluations, the program seemed beneficial. As with most beneficial endeavors, there was an increase time requirement by both the students and faculty to initiate and coordinate the process. The results however appear to far overshadow this slight increase in time commitment.

**Lessons Learned**

In the planning stages of CIVE 650 Civil Capstone Design, there was a concern by the faculty that some of the student groups would be unable to identify and obtain the services of at least one external collaborator / mentor. The initial fear of the faculty that was unfounded. All of the student design groups were successful in obtaining the assistance of at least one professional to act as a mentor, with many groups, as see in Table 1, having several mentors with expertise in various sub-disciplines of civil engineering. One group in fact, had eleven. Throughout the course of the semester, it became apparent that such a large group of mentors is difficult to coordinate and keep abreast of the students' progress. Thus it is planned that the next time the course is run, to limit the number of mentors to five. This would translate into one per student.

A second issue that surfaced during the semester was the amount of expertise the mentors had. Though most of the mentor identified by the students were licensed Professional Engineers with many holding senior positions in their firm, a few of the mentors identified were recent graduates. These recent graduates lack enough practical experience to meaningfully assist the student design groups. These younger engineers were too inexperience to act as effective mentors. In light of this, it is proposed that the next time the course is run all mentors have a minimum of five years of experience.

The third and final lessoned learned during the semester arose from the fact that in engineering there is often numerous solutions to a particular problem. Though a seasoned engineering is aware of this, many students are not. There were a few instance during the design phase of the course were a faculty advisor would recommend the students to approach a problem in one way, while the external mentor unbeknown to the faculty recommended another. Though both approaches were correct, these conflicts in directions caused delay and required portions of the student project to be reworked, thus resulting in unhappy students. Moving forward, at the beginning of the semester a discussion with the students about differences in design methods is planned. Additionally, all recommendations by the mentors need to be reviewed by the faculty and the faculty have final say in the method chosen.

**Conclusion**

The introduction of the requirement for student groups in a senior capstone course to identify and obtain the services of at least one External Collaborator (Mentor) has numerous benefits as highlighted in first year of incorporating the requirement into CIVE650 Civil Capstone Design at Wentworth Institute of Technology. The use of such mentors with the suggested minor changes is planned again for the next semester the course is run at Wentworth Institute of Technology.

# Outcomes of an interdisciplinary, dual-mentor doctoral training program in Nanomedicine

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## Abstract

The Nanomedicine program at Northeastern University is a multi-year specialization program designed to supplement traditional graduate education in science and engineering. Since 2006, the program has recruited 50 doctoral students to perform a combination of experiential two or more mentors. Interdisciplinary scholarly outputs were tracked through progress reports, surveys, and online databases. Both Nanomedicine trainees and mentors reported a significant increase in interdisciplinary activities, including publications, presentations, and funded research proposals, as a direct result of the program. To determine whether trainees were sufficiently prepared for a career in Nanomedicine, graduates of the program were tracked through social media. Nearly 90% of graduates were found to have pursued careers in health care. Currently, 43% of graduates continue to perform research or develop products that directly involve Nanomedicine. Lessons learned from this program are now being applied to an undergraduate co-op program in cancer nanomedicine.

## Keywords

Nanomedicine, IGERT, nanotechnology, nanoscience, graduate training, education

## Introduction

The Nanomedicine program at Northeastern University was established in 2005 in response to a call from the National Science Foundation (NSF) to develop broad-based graduate education programs centered on an interdisciplinary research theme. Participants in this multi-year Integrative Graduate Education and Research Traineeship (IGERT) program receive training and education in nanomedicine while continuing to acquire deep knowledge in their chosen doctoral field. Activities specifically developed for trainees include specialized courses, a weekly seminar series, formalized co-mentoring for each student, an internship requirement, and outreach activities. More details about this program are described in [1]. Here we describe how this program was implemented and report on metrics of success.

## Implementation

Participants were chosen in a highly competitive application-based process from among students already admitted to science, technology, engineering, and mathematics (STEM) doctoral programs at Northeastern University. Selection criteria included research proposal quality and relevance, scholastic ability, motivation, and professional accomplishments. The Nanomedicine program has admitted 50 doctoral students across ten different departments to-date, including two departments unique to our partner institutions (Figure 1). The first entrants into the program came primarily from the Biology, Chemistry, Pharmaceutical Sciences, and Physics departments. As the engineering programs at Northeastern University became more multidisciplinary, combined with expanded recruitment activities, we observed increased representation from students of Bioengineering and Chemical Engineering. In total, 42% of trainees were recruited from engineering disciplines and 58% recruited from other STEM disciplines. Of these 50 trainees, 50% have completed their Ph.D., 44% are progressing toward their Ph.D., with 6% have completed a terminal M.S. degree. The program's commitment toward diversity is exemplified by the fact that 54% of trainees were women and 22% were underrepresented minorities.

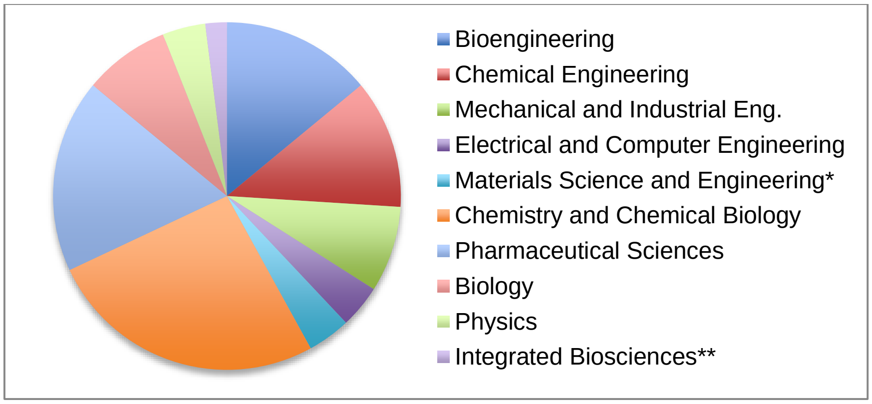


**Figure 1.** Trainee recruitment from STEM disciplines (2006-2014). Adapted from [1].
* Offered at Tuskegee University only. **Offered at University of Puerto Rico – Mayaguez only.

The challenge of integrating students from diverse fields into a highly interdisciplinary program was accomplished through use of co-mentoring. As part of the competitive application process, each potential trainee was asked to propose a nanomedicine research project that could be conducted from at least two different perspectives within different laboratories (and if appropriate, via an internship as well). For some students, the proposed research was a continuation of their primary thesis project; for others, it was an opportunity to develop a new secondary research direction. Trainees were asked to select at least one scientific co-mentor during the application process; however, many took the initiative to cultivate additional mentors over their 2-year training period (Table 1). Sources of formal and informal mentorship were identified from trainee progress reports, meetings, interviews, and publications.

**Table 1.** Trainee utilization of mentoring during their Nanomedicine research project (2006-2014), from [1].

| **Sources of formal mentorship** | **# Trainees** |
|---|---|
| Faculty in home department | 44 (88%) |
| Faculty outside home department | 32 (64%) |
| Clinicians and/or clinical researchers | 15 (30%) |
| Faculty at other academic institutions | 18 (36%) |
| Professionals from other sectors (industry, government, etc.) | 4 (2%) |

For the purposes of our study, sources of mentorship were defined as individuals whom: 1) provided significant scientific guidance (as indicated by the trainees) and 2) were listed as a contributor in at least one first-author manuscript prepared by the trainee. Of the 50 trainees, 90% had at least two or more mentors, with an average of 2.9 mentors/student. Overall, there was a high tendency for students to have their primary Nanomedicine mentor in their home department (88% of students); however, 80% of trainees also had at least one mentor outside of their department or institution. Notably, 30% of students had at least one clinician or clinical researcher as a mentor. These clinical mentors included representatives from Boston local hospitals, as well as several clinicians from other states. According to the trainees, many of these mentors were specifically acquired for their Nanomedicine projects and had not previously published together with the trainees' primary mentor. In total, the research arm of the Nanomedicine program has brought together 75 mentors, including 38 from Northeastern University and 40 from outside institutions [1].

## Outcomes

Program outcomes were assessed through several different metrics. Using a Web-based portal though which students provided yearly progress updates during and following training, we tracked the scientific output of each trainee, including the publication of manuscripts and the presentation of data at conferences. The cumulative number of publications and presentations are shown by trainee entry year in Figure 2. Nanomedicine trainees have published 117 peer-reviewed manuscripts and presented at 189 conferences to date. Students who graduated with a PhD produced an average of 3.9 manuscripts and 4.1 conference presentations directly related to their Nanomedicine project [1]. When the cumulative statistics are compiled by the year of trainee entry (Figure 2), the rate manuscript output is observed to highest for years 2006–2010, when trainees were generally joined the program in their 3rd or 4th year of graduate school. For students admitted after 2010, whom were generally admitted after their 1st year of graduate studies, manuscripts are now emerging. The presentation of research findings, either through oral or poster presentations, has held relatively constant, at an average of 4.2 □□1.6 presentations per student, likely due to the program's requirement for students to regularly participate in such events during the fellowship period.

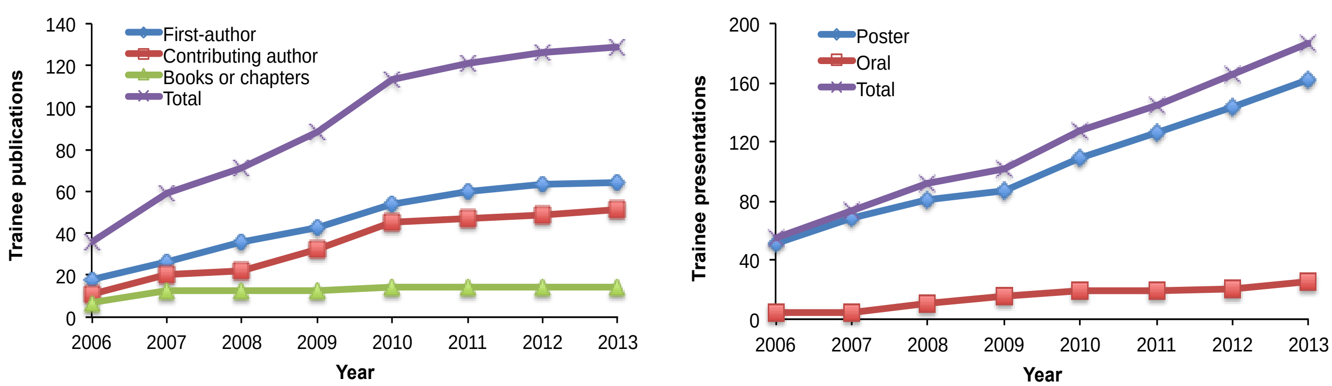


**Figure 2.** Cumulative academic outputs directly related to IGERT nanomedicine research projects (2006-2014), sorted by year of trainee entry into the program. From [1].

The career paths of nanomedicine graduates were tracked through social media and personal communication (Table 2). Of the 28 trainees who completed their terminal degree (including 3 M.S. students), 25 are currently pursuing careers in the health care sector. This number is particularly striking considering many of their home disciplines are not considered traditional feeders for the healthcare sector. 48% of those employed in health care (43% of total) are currently performing research or developing products that directly involve nanomedicine, including nanoparticle-based assays for bioanalyte detection (n=6), nanoparticle-based biosensors (n=2), nanoformulation of pharmaceuticals (n=3), and food packaging (n=1). This data is in strong agreement with career trajectory data reported by the NSF, which indicates that IGERT students are more likely to pursue an interdisciplinary career path and that approximately 51% of graduates find employment in jobs that draw upon the disciplines they used for their dissertation research [11].

**Table 2.** Trainee career paths following graduation, from [1].

| Career Path | Healthcare | Nanomedicine |
|---|---|---|
| Industry (n=12) | 12 | 4 |
| Academia (n=9) | 8 | 6 |
| Education (n=3) | 2 | -- |
| Entrepreneurship (n=2) | 2 | 2 |
| Intellectual Property (n=1) | 1 | -- |
| Consulting (n=1) | -- | -- |
| **Total (N=28)** | **25 (89%)** | **12 (43%)** |

Program impacts on faculty activities were assessed by survey. Faculty members of Northeastern University and partner institutions who participated as mentors for at least one year (n=38) were asked via a one-time yes/no survey about how the Nanomedicine program has directly affected their research. Of the 25 respondents, 100% reported that participation in the Nanomedicine program enhanced their own interdisciplinary activities in at least one way.

**Table 3.** Program impacts on faculty activities, from [1].

| As a direct result of the Nanomedicine program, I have: | Percent of faculty (N=25) |
|---|---|
| Worked on projects with individuals outside my home discipline | 96% |
| Co-authored proposals with individuals outside my home discipline | 84% |
| Mentored students outside my home discipline | 52% |
| Participated on thesis committees outside my home discipline | 68% |
| Published research findings in journals outside my home discipline | 80% |
| Presented new research findings at conferences outside my home discipline | 76% |
| Received new research grants, either singly or as part of a team | 56% |

## Discussion and Conclusions

The creation of a training program in Nanomedicine is highly challenging because this field attracts students from diverse disciplines and requires them to acquire both breadth and depth of knowledge to succeed in their chosen career path [2-5]. We believed it was beneficial to implement a 2-year, cross-departmental fellowship program, similar to several other well-established IGERT models [6-9], rather than a formal degree-granting program in order to: 1) establish a large pool of potential students, 2) facilitate the formation of new collaborations across faculty of different disciplines, and 3) ensure that trainees continue to acquire depth of knowledge in their chosen department. Thus, the program utilizes a "value-added" strategy to expand interactions across disciplines without diluting disciplinary credentials or the other benefits of membership in a single department [1].

Given the requirement for a dual-mentoring structure, a variety of activities were offered to expose trainees to a broad cross-section of researchers, clinicians, entrepreneurs, professionals, and civil servants. Opportunities for both formal and informal interactions were provided, including lunches, workshops, and internships, in order to expose the students to a variety of career paths and to enrich their understanding of the skills required for success. Trainees clearly took advantage of these opportunities to cultivate a variety of mentors with whom they later published one or more manuscripts. In focus groups and one-on-one interviews, trainees acknowledged that co-mentoring by faculty members from other disciplines broadened their thinking, and in particular, their approach to solving research challenges. This is in agreement with other successful IGERT programs, in which trainees reported more frequent interactions with mentors across departments [11]. The broad range of mentors cultivated by nanomedicine trainees suggests that students successfully identified areas in their research that would benefit from additional mentorship. It is particularly gratifying to see that 30% of trainees published with mentors who had clinical expertise. We believe this indicates that nanomedicine trainees recognized the importance of clinical collaboration for producing clinically relevant research.

A major concern of interdisciplinary training is whether it is sufficiently academically rigorous to prepare students for future careers. Here we saw that 89% of graduates pursued careers in health care, even though many of their home disciplines are not considered as traditional feeders for the health care sector. Those who chose careers in nanomedicine (48% of entrants into health care) were successful in identifying a variety of career paths and were not limited to academia alone. Taken together, we believe these statistics suggest that the trainees understood their interdisciplinary training and that this training was sufficiently rigorous enough to prepare them for a career in nanomedicine. There also appears to be a clear path for academic success in nanomedicine, despite the limited federal funding structure for nanomedicine. We observed that nanomedicine mentors are more significantly more likely ($P<0.05$) to perform research (96% vs 78%), publish (80% vs 48%), carry out presentations (76% vs 44%), and apply for grants (84% vs 64%) with colleagues across departments than faculty members who do not participate in interdisciplinary programs [10]. Most excitingly, 56% of faculty members who submitted interdisciplinary proposals in Nanomedicine succeeded in obtaining funding. Reports issued by the NSF indicate that participation in an IGERT program increases the likelihood of interdisciplinary funding by an average of 19% [10], placing the nanomedicine funding success rate well above average. Thus for graduates who chose academic careers, there is a clear opportunity to perform research, publish, carry out presentations, and receive grants within this interdisciplinary field.

In conclusion, the Nanomedicine program at Northeastern University is a mature training and education program with a proven record of success for placing doctoral graduates into a variety of health care and nanomedicine careers. This program has the capacity to integrate trainees from both sciences and engineering, provide sufficiently rigorous training for students to acquire both breadth and depth of knowledge in nanomedicine, and provide trainees with the skills necessary to pursue a long-term careers in nanomedicine.

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## References

1 van de Ven AL, Shann MH, Sridhar S. "Essential components of a successful doctoral program in nanomedicine." International Journal of Nanomedicine. 2015;10:23-30.

2 Murday JS, Siegel RW, Stein J, Wright JF. "Translational nanomedicine: status assessment and opportunities." Nanomedicine (Lond). Sep 2009;5(3):251-273.

3 Pautler M, Brenner S. "Nanomedicine: promises and challenges for the future of public health." International Journal of Nanomedicine. 2010;5:803-809.

4 Velez JM, Velez JJ. "The eminent need for an academic program in universities to teach nanomedicine." International Journal of Nanomedicine. 2011;6:1733-1738.

5 Tsai-hsuan Ku S. "Forming interdisciplinary expertise: one organization's journey on the road to translational nanomedicine." Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology. 2012;4(4):366-377.

6 Martin PE,Umberger BR."Trends in interdisciplinary and integrative graduate training: an NSF IGERT example." Quest. 2003;55(1):86–94.

7 Cowan K, Gogotsi Y. "The Drexel/UPenn IGERT: Creating a new model for graduate education in nanotechnology." The Journal of Materials Education. 2004;26(1-3):147-152.

8 Drezek KM, Olsen D, Borrego M. "Crossing disciplinary borders: A new approach to preparing students for interdisciplinary research." Paper presented at: Frontiers in Education Conference, 2008. FIE 2008. 38th Annual; 22-25 Oct. 2008, 2008.

9 Moslemi JM, Capps KA, Johnson MS, et al. "Training tomorrow's environmental problem solvers: An integrative approach to graduate education." BioScience. June 1, 2009 2009;59(6):514-521.

10 Abt Associates Inc. Evaluation of the initial impacts of the NationalScience Foundation’s Integrative Graduate Education and Research Traineeship Program. The National Science Foundation; 2006; Virginia, US.

11 Abt Associates Inc. Evaluation of the National Science Foundation’s Integrative Graduate Education and Research Traineeship Program (IGERT): follow-up study of IGERT Graduates. National Science Foundation; 2011; Virginia, US.

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# Students' Opinions on Online Assessments in an Introductory Engineering Course

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***Abstract*—Online education tools and course assessment tools available in web-based software like Blackboard have been becoming a more and more popular supplementation to traditional face-to-face classroom instruction. An example of these tools is Blackboard's assessment features that provide instructors with tools for building online assessments using different question types and different question options. The purpose of this work is to examine how students view online assessment in introductory engineering courses like statics. Quizzes and tests with mostly formula type questions were used for assessment in this study. Through the use of assessment tools and options available, tests and quizzes were designed so that each student obtained different versions of the exam or the quiz. At the end of semester, surveys were distributed to obtain student feedback on the assessment methods. The questionnaires were designed to obtain a student's response on effectiveness, scheduling, flexibility, and learning robustness, to name a few. As a result, this study found that students prefer certain aspects of online assessment. This assessment type allows students more freedom and flexibility in taking exams and quizzes, provides opportunities for self-improvement, and gives students timely feedback. Students also find this assessment type less stressful. The biggest drawbacks found for the students in this work were that there was no partial credit for problems that were partially correct as students would normally see on paper based assessments and the ease at which they felt their fellow classmates could cheat on these online assessments.**

## I. INTRODUCTION

ONLINE education is gaining momentum throughout the world due to faster internet and availability of modern mobile technologies such as smart phones, PDA's, ipad's, tablets, etc. Engineering programs are still mostly face-to-face all over the US. However, there are some engineering programs in the US that are also offering some full online as well as hybrid engineering courses. Whether a program or a course is online or not, the tests or the quizzes can be given online to students to assess their performance. Research on online teaching and online assessments that replace traditional paper-based tests and quizzes have been a point of focus by many researchers. It is a very common tradition for many instructors to provide a quiz on material that he or she is going to cover next. That way the students can study and be prepared to comprehend the lecture effectively. A study [1] shows that engineering students are more engaged if they take online quizzes right before they come to class. Acceptance of online testing among engineering students may not be so much different from the online testing among students in any other discipline.

A study [2] was performed to investigate student perceptions regarding online testing in a managerial accounting course and they were found to be mixed with both positive and negative attitudes towards the testing. However, a similar study in engineering is highly scarce. One advantage for online testing is that the test takers can see their performance during or right after taking their tests or quizzes. A study [3] suggests that test takers perform better in computer-based tests since they can see their performance. To enhance the learning experience of students with technology besides desktop computers, PDA's and cell phones are now also being used in many institutes. A study [4] showed that a PDA-based quiz is more efficient compared to a paper-and-pencil based one in terms of the time it takes to finish the quiz.

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From the instructors' perspectives the use of online testing is somewhat mixed. A study [5] suggests that grading for online assessments are easier compared to the traditional ones; however, giving feedback to the students is just the opposite. From another instructor's perspective [6] an online testing is hard to setup, however, effective to provide feedback to the students in a personalized and timely manner.

In the current study, an effort is made to assess the acceptance of online assessments (tests/quizzes) among the engineering students for a statics class.

## II. METHODOLOGY

Online assessments were given to a mid-size introductory engineering course such as Statics during the long summer of 2013. Formula-based problems were given to the students in the current study through the quizzes and the tests in Blackboard. The students were allowed to take those assessments during a specified time period outside of the regular class period. The formula-based questions were randomly generated for different students as well as for different attempts for the same student. That makes numerous versions of a test and as well makes it almost impossible to have identical tests for two different students. Students were allowed to take the tests or quizzes multiple times and each time a student took a quiz/test, he or she got a different version of that test/quiz.

A survey was conducted towards the end of the semester to see the acceptance of the Blackboard assessments as compared to the paper-based ones. The survey questions were given to the class of thirty-six students to obtain the perceptions of students towards the online testing through Blackboard. The Statics class where the survey was given was entirely a traditional face-to-face type class. The survey instrument was taken from a work related to introductory managerial accounting performed in a similar study [2]. The survey questions were slightly modified to fit the purpose of the current study. The survey results were discussed in details. The survey questions are shown in the appendix section of this paper.

## III. RESULTS AND DISCUSSION

The survey results were found to be interesting. Students' responses to the survey questions are given here in Table 1.

Table 1: Survey results

| # | Question | Score | # | Question | Score |
|---|---|---|---|---|---|
| 1 | When compared to paper-based tests that require writing or detailed computations, does computerized testing make the exam: | 3.61 | 5 | To what extent do you think that computerized testing affects a student's overall stress and anxiety levels? | 4.03 |
| 2 | To what extent do you think that computerized testing affects the scope (in other words, the quantity and type) of the material that can be used? | 3.54 | 6 | To what extent do you think that computerized testing affects the opportunity to cheat? | 2.47 |
| 3 | To what extent do you think that exams/quizzes administered in a computerized format affect the perception of the quality of the grade earned? | 3.22 | 7 | Computerized testing allows students to take an exam within a specified time frame or "window" of multiple days. In your opinion, do students taking the exam near the end of this period | 2.92 |
| 4 | To what extent do you consider the following factors to be positive or negative aspects of computerized testing in engineering | | 8 | Computerized testing requires a student to look at a computer screen for an extended period of time. To what extent do you think that this affects test performance? | 3.03 |
| | a) Flexibility of scheduling and taking exams | 4.69 | 9 | Do you think that computerized testing limits making notes while taking the exam or quiz? | 3.28 |

| | | | | | |
|---|---|---|---|---|---|
| | b) Permits more prompt feedback on exam performance than traditional paper-based testing | 4.36 | 10 | Do you think computerized testing limits a student’s ability to quickly review the entire exam and budget time by guessing how much work is left? | 3.42 |
| | c) Objective format permits educated guessing of answers | 3.19 | 11 | The speed of the computer or screen size may impact a student’s ability to scan through the exam and review “answered” or “unanswered” questions. To what extent do you think this affects exam performance? | 2.86 |
| | d) Elimination of essay questions or long-term problems | 3.78 | 12 | In a computerized testing a student can be allowed to take the test multiple times. Do you think the multiple attempts enhance the learning process and make a student skilled about the material covered in the test or quiz? | 4.53 |
| | e) Elimination of judgment in grading (answer is either right or wrong) | 3.22 | 13 | In a computerized testing do you prefer to have multiple choice questions or putting a single numerical (calculated) answer in the answer box? | 3.42 |
| | f) Elimination of partial credit in grading | 2.44 | 14 | Do you believe that separate tests or long-form problems, should be given in addition to computerized testing | 3.28 |
| | g) Requirement that student be knowledgeable about computers | 3.31 | 15 | Do you believe that computerized testing accurately measures a student’s learning? | 3.75 |
| | h) Elimination of in-class return and review of exams | 3.33 | 16 | In the current computerized testing for a given problem only a single-part question can be asked. Do you prefer to have multi parts of the same problem? | 3.25 |

The survey results are also shown in the following graph in Figure 1. It is noted that for all of the questions three represents neutral perception toward the online testing for a given question. Some of the results obtained were expected while others were not anticipated. Students’ responses to the survey questions are discussed here in details. The first question students were asked was if paper based assessments are easier or if computer based assessments are easier. In this question it was expected that students would say that computer based assessments were easier than paper based. The result was a 3.61 indicating that students thought that computer based assessments are slightly easier than paper based assessments. The perception as to why it is easier is explained with the results of later questions. The second question asked students if computer based assessment expands or limits the scope (quantity and type) of material that can be covered in an assessment. Students surveyed felt that online assessment allowed for an increased scope of material that could be covered.

In the next question, students were asked how the computerized format affected the perception of the quality of the grade they earned. It was expected that the students would feel that the grade they earned was of the same quality whether it was paper based or computer based. However, students felt that the quality of their grade was higher with computer based assessments over paper based assessments. The next set of questions asked students if the factor was a positive or negative aspect of online assessment. The first factor was the flexibility of scheduling and taking online assessments. This is one question the students felt the strongest about. Students rated this 4.69 out of 5.00 indicating that they felt that the flexibility online assessment offered was a major positive factor. It allowed them to choose a time in a set time frame where they could sit down and take the online assessment at their convenience.

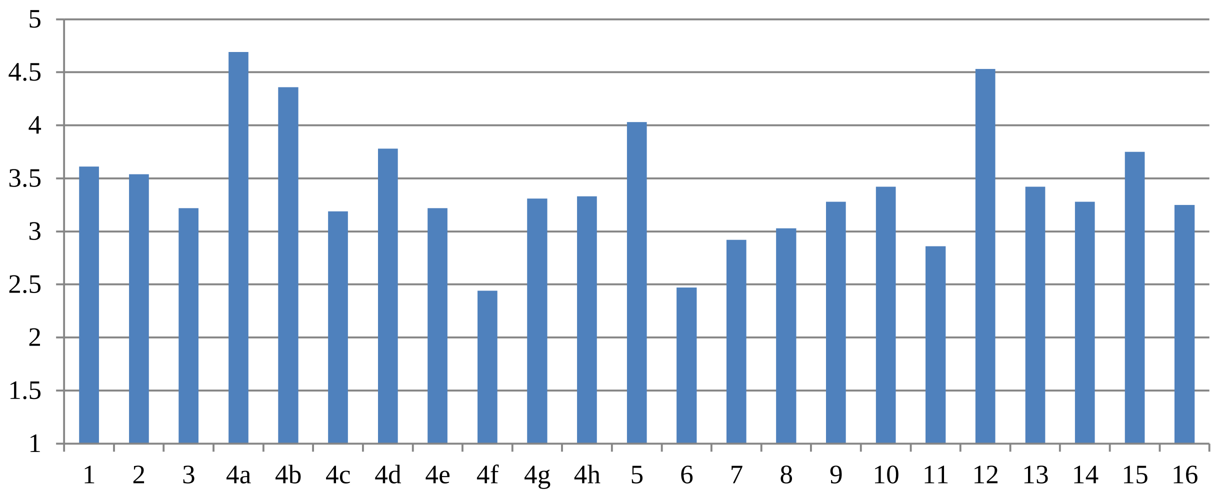


Fig. 1: Survey scores

The second factor they were asked about was the positivity or negativity of the prompt feedback available for online assessment versus traditional paper based assessment. Students also had a strong opinion on this and felt that this was a very positive aspect. This allowed them to know almost instantly if they were right or wrong in their answering of the questions. The next factor students were asked to rate as positive or negative was the ability to make an educated guess on the online format. Students said that this was a slightly positive aspect of the online assessments – if they did not know the answer they could look at the possible options and make an educated guess as to what the correct answer might be. The next factor that the students rated was if the elimination of essay and long problems on online assessment was positive or negative. Students felt that this factor was somewhat positive, rating it a 3.78 out of 5.00.

The next factor on the survey to be rated as positive or negative was the elimination in judgement of grading, either the answer is correct or it is wrong, no gray area in between. Students felt that this was a slightly positive factor in online assessment. The next factor student were asked about on the survey was the elimination of partial credit for partially correct answers. As expected students felt that this was one of the major drawbacks of online assessments. Students rated this question a 2.44 out of 5.00 showing a negative aspect. The next factor asked the students if needing a working knowledge of computers was a negative or positive factor of online assessments. Students felt here that students need to be somewhat knowledgeable about computers in order to be successful at online assessments.

The final factor that students were asked to rate as a positive or negative aspect of online assessments was if the elimination of in-class return and review of exams was a positive or negative aspect of online assessment. It was expected that students would see this as a big drawback of online assessment but the survey showed that students felt that this was a slightly positive aspect of online assessment. It could be that students feel that in-class return and review of exams is a waste of time since students receive their grade and feedback almost instantly on an online assessment. The next question students were asked on the survey was how much online assessments increased or decreased their stress. Students clearly indicated that they felt online assessment reduced their stress levels in comparison to paper based assessments.

The sixth question on the survey asked students if they felt that online assessment made it easier or harder to cheat. Students indicated that it was slightly easier to cheat on online assessment than it was to cheat on paper based assessment. The next question students were asked was if they felt that taking the assessment at the beginning of the time period gave an advantage or if taking the assessment at the end of the given time period gave an advantage. This question was asked hoping that students would not find any advantage one way or the other. In this survey it was neutral. If it was not neutral this is something that would need to be looked at much closer. The next question asked the students if looking at the computer screen for long periods of time while taking an online assessment had a negative or positive effect on their performance. This question was also asked hoping that students would not find it as having a negative or positive effect on his/her performance. In this survey it indeed was found to be neutral. Again as stated for the previous question, if this had come out as a negative or positive it would warrant further investigation.

Question number nine asked the students being surveyed if they felt that online assessment limited their ability to take notes while doing the assessment. Students responded that they slightly disagree that it limited their ability to take notes. The next question on the survey asked students if computerized testing limited their ability to quickly review the entire exam and budget time by guessing how much work was left. Students responded that they felt that in an online exam seeing all the questions on the screen from the beginning actually helped them to more quickly review the entire exam and budget their time more quickly by estimating how much work was left.

The next question of the survey asked students about how computer speed and screen size affect their performance. Students responded saying that it had a slight negative effect indicating that computer speed and screen size are important when taking an online assessment. The next question was a very important question. This question asked students if multiple attempts enhanced their learning process and made them more skilled about the material covered in the test or quiz. For this question it was expected that students would agree that it increases student learning. This was the exact response that was found through the survey with a response of 4.53 out of 5.00. This happens because the students are allowed to take the online assessment many times. Each time the student takes the assessment they get a different set of questions so this forces the students to practice the material as well as the procedure needed to correctly solve the problem. Each time a student works through the question in hope of getting a higher grade they are gaining more mastery over the type of question being asked.

The thirteenth question on the survey asked students if they preferred multiple choice type questions or a single numerical answer question. In this question it was found that students prefer multiple choice type questions over numerical questions. It has been assumed that this is because students prefer the multiple choice questions because in multiple choice questions there are no calculations involved that could lead to a wrong answer from something as simple as a rounding error. As well students would be able to make an educated guess if they did not know the answer in multiple choice type questions.

The next question the survey asked students was if they thought a separate test should be given for long problems. The results from the survey indicated that students did not have a preference if an additional assessment was given for long problems or not given for long problems. The next to last question students were asked on the survey was if they believed that online student assessment accurately measured their learning. Students responded with an average answer of 3.75 indicating that they felt that the online assessment almost accurately measured their learning. The last question listed on the survey for students to respond to asked them if they preferred to have multi parts in the same problem where if someone answered one part incorrectly still on the other part(s) he/she may answer them correctly or if they preferred the current one problem part per question. Students responded to this question saying that they had no preference if it was in one question or in multiple questions.

At the end of the survey students were given an area where they could feel free to make comments. All of the comments were read and most of the comments were from students supporting the multiple attempts and how it helped them to master the material more. (Note: comments were written exactly as students wrote them.) For example, Student 7 said, "…I personally have been able to relearn and discover errors in my work because of the option of multiple attempts, therefore increasing my understanding of the subject matter…". Another comment from Student 8 said, "…multiple tries made me better understand the problem intricately…". Student 9 also said, "… with multiple attempts I take longer on exams and it truly forces me to understand the material…". Student 26 said that they liked immediate feedback offered by online assessments because, "… I believe online testing can give immediate feedback so that the student may correct or continue to work on problems they got wrong…". A final comment worth mentioning came from Student 33 said, "…I really like computerized testing because we have several attempts. Find because of this we can practice and learn more."

## IV. CONCLUSIONS

To summarize here the most important parts of the survey were that students felt that online assessment was easier because it gave them flexibility in when they could take the exam, it was easier because it reduced their stress in taking the assessment, and that online assessments offered almost instant feedback on how they were performing. Also, students felt that taking online assessments greatly increased their learning and mastery of the material being covered. The biggest drawbacks that the students found were that there was no partial credit for partially correct answers, that it was easier to cheat on online assessments than paper based assessments, and that the computer speed and screen size if not fast enough and big enough could have a negative effect on their performance. Overall the students had a more positive attitude than negative attitude towards online testing supported by the survey answers and the comments made by the students.

## APPENDIX

Table 2: Survey questionnaire

| Course: Statics | | Instructor: | | | Date: | |
|---|---|---|---|---|---|---|
| 1 | When compared to paper-based tests that require writing or detailed computations, does computerized testing make the exam: | Much more difficult | More difficult | No effect on difficulty | Easier | Much easier |
| | | 1 | 2 | 3 | 4 | 5 |
| 2 | To what extent do you think that computerized testing affects the scope (in other words, the quantity and type) of the material that can be used? | Strongly limits scope | Limits scope | No effect on scope | Expands scope | Strongly expands scope |
| | | 1 | 2 | 3 | 4 | 5 |
| 3 | To what extent do you think that exams/quizzes administered in a computerized format affect the perception of the quality of the grade earned. | Strongly weakens perception of quality | Weakens perception of quality | No effect on perception of quality | Improves perception of quality | Strongly improves perception of quality |
| | | 1 | 2 | 3 | 4 | 5 |
| 4 | To what extent do you consider the following factors to be positive or negative aspects of computerized testing in engineering | Very negative | Negative | Neither positive or negative | Positive | Very positive |
| | | 1 | 2 | 3 | 4 | 5 |
| | a) Flexibility of scheduling and taking exams | 1 | 2 | 3 | 4 | 5 |
| | b) Permits more prompt feedback on exam performance than traditional paper-based testing | 1 | 2 | 3 | 4 | 5 |
| | c) Objective format permits educated guessing of answers | 1 | 2 | 3 | 4 | 5 |
| | d) Elimination of essay questions or long-term problems | 1 | 2 | 3 | 4 | 5 |
| | e) Elimination of judgment in grading (answer is either right or wrong) | 1 | 2 | 3 | 4 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | f) Elimination of partial credit in grading | 1 | 2 | 3 | 4 | 5 |
| | g) Requirement that student be knowledgeable about computers | 1 | 2 | 3 | 4 | 5 |
| | h) Elimination of in-class return and review of exams | 1 | 2 | 3 | 4 | 5 |
| 5 | To what extent do you think that computerized testing affects a student's overall stress and anxiety levels? | Strongly adds stress | Adds stress | No effect on stress | Reduces stress | Strongly reduces stress |
| | | 1 | 2 | 3 | 4 | 5 |
| 6 | To what extent do you think that computerized testing affects the opportunity to cheat? | Much easier to cheat | Easier to cheat | No effect on cheating | Difficult to cheat | Much more difficult to cheat |
| | | 1 | 2 | 3 | 4 | 5 |
| 7 | Computerized testing allows students to take an exam within a specified time frame or "window" of multiple days. In your opinion, do students taking the exam near the end of this period | Have a strong disadvantage compared to those taking it earlier | Have a disadvantage compared to those taking it earlier | Have neither an advantage or disadvantage compared to those taking it earlier | Have an advantage compared to those taking it earlier | Have a strong advantage compared to those taking it earlier |
| | | 1 | 2 | 3 | 4 | 5 |
| 8 | Computerized testing requires a student to look at a computer screen for an extended period of time. To what extent do you think that this affects test performance? | Very negative effect on test performance | Negative effect on test performance | No effect on test performance | Positive effect on test performance | Very positive effect on test performance |
| | | 1 | 2 | 3 | 4 | 5 |
| 9 | Do you think that computerized testing limits making notes while taking the exam or quiz? | Strongly agree that taking notes is limited | Agree that taking notes is limited | No effect on taking notes | Disagree that taking notes is limited | Strongly disagree that taking notes is limited |
| | | 1 | 2 | 3 | 4 | 5 |
| 10 | Do you think computerized testing limits a student's ability to quickly review the entire exam and budget time by guessing how much work is left? | Strongly decreases the ability to quickly review the exam | Decreases the ability to quickly review the exam | No difference between online testing and paper-based testing in terms of reviewing the exam | Increases the ability to quickly review the exam | Strongly increases the ability to quickly review the exam |
| | | 1 | 2 | 3 | 4 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | The speed of the computer or screen size may impact a student's ability to scan through the exam and review "answered" or "unanswered" questions. To what extent do you think this affects exam performance? | Very negative effect on test performance | Negative effect on test performance | No effect on test performance | Positive effect on test performance | Very Positive effect on test performance |
| | | 1 | 2 | 3 | 4 | 5 |
| 12 | In a computerized testing a student can be allowed to take the test multiple times. Do you think the multiple attempts enhance the learning process and make a student skilled about the material covered in the test or quiz? | I strongly disagree that it will increase student learning | I disagree that it will increase student learning | No effect on student learning | I agree that it will increase student learning | I strongly agree that it will increase student learning |
| | | 1 | 2 | 3 | 4 | 5 |
| 13 | In a computerized testing do you prefer to have multiple choice questions or putting a single numerical (calculated) answer in the answer box? | I strongly prefer a single numerical answer to be typed in the answer box | I prefer a single numerical answer to be typed in the answer box | I do not have any preference | I prefer multiple choice type questions | I strongly prefer multiple choice type questions |
| | | 1 | 2 | 3 | 4 | 5 |
| 14 | Do you believe that separate tests or long-form problems, should be given in addition to computerized testing | I strongly believe a separate test should be given | I believe a separate test should be given | I do not have any preference | I believe a separate test should not be given | I strongly believe a separate test should not be given |
| | | 1 | 2 | 3 | 4 | 5 |
| 15 | Do you believe that computerized testing accurately measures a student's learning? | I strongly disbelieve it accurately measures learning | I disbelieve it accurately measures learning | I do not have any preference | I believe it accurately measures learning | I strongly believe it accurately measures learning |
| | | 1 | 2 | 3 | 4 | 5 |
| 16 | In the current computerized testing for a given problem only a single-part question can be asked. Do you prefer to have multi parts of the same problem? For a multi-part | I strongly prefer to answer single-part questions | I prefer to answer single-part questions | I do not have any preference | I prefer to answer multiple-part questions | I strongly prefer to answer multiple-part questions |
| | | 1 | 2 | 3 | 4 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | problem if someone answers a part incorrectly, still the other part(s) he/she may answer correctly. Example of a multi-part problem: The sides of a rectangular block are given as 2 m, 3 m, and 4 m. Find a) the total surface area of the block and b) the volume of the block. | | | | | |
| 17 | Please use the following space to provide comments or to explain answers to your questions. We are very interested in knowing your perceptions. | | | | | |

REFERENCES


[1] Cashman, E.M.,Eschenbach, E.A., "Using on-line quizzes outside the classroom increase students engagement inside the classroom", ASEE, Spring 2003 Conference Proceedings.

[2] Apostolou B., Blue, M.A., Daigle, R.J., "Student perceptions about computerized testing in introductory managerial accounting", J. of Acct., Ed. 27 (2009) pp. 59-70

[3] Wise, S. L., Plake, B. S., Pozehl, B. J., Barnes, L. B., & Lukin, L. E., "Providing item feedback in computer based tests: effects of initial success and failure", Educational and Psychological Measurement, 1989

[4] Noa Segal, Toni L. Doolen, J. David Porter, "A usability comparison of PDA-based quizzes and paper-and-pencil quizzes", Computers and Education, Vol 45, 2004, pp. 417-432

[5] Tamara Knott, Steve York, "A comparison of on-line and traditional testing methods", American Society for Engineering Education, 2006-2238

[6] Edward Gehringer, "Online vs. on-paper exams", American Society for Engineering Education

# Ensuring Attainment of ABET Criteria 4 and Maintaining Continuity for Programs with Moderate Faculty Turnover

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## Abstract

Attaining ABET Criterion #4 – Continuous Improvement can be challenging for schools that experience moderate faculty turnover, and/or heavily rely on adjunct instructors. In this paper we present an End of Course Review (EOCR) process that serves as a means to achieve this objective. The EOCR process instills a culture of assessment in all our faculty, both junior and senior alike, and also ensures program quality and course continuity.

## Keywords

Assessment, ABET, Faculty turnover

## Introduction

This paper will describe a process that ensures the attainment of ABET Criteria 4 as well as maintain course continuity for programs that experience high faculty turnover. It is a based on a paper that will be presented at the 2015 ASEE Conference in Seattle[1].

*A. Program Quality, Assessment and Accreditation*

The goal of an undergraduate engineering program is for its graduates to attain the stated program objectives. Stakeholders expect such achievement. An engineering program's quality is ensured by satisfying the criteria provided by ABET. This criteria serves as a means of a program's *quality control* and *improvement*. The criterion includes attainment of student outcomes, and continuous improvement. ABET's Criterion 4, states the following[2]:

> *"The program must regularly use appropriate, documented processes for assessing and evaluating the extent to which student outcomes are being attained. The results of these evaluations must be systemically utilized as input for the continuous improvement of the program."*

Note the emphasis on *assessment*, *documented process*, *attainment*, and *continuous improvement.*

To achieve the ABET mandate for engineering programs, the U.S. Coast Guard Academy (USCGA) has adopted an assessment process as described by Colella[3] and diagramed in Figure 1. The process shown in Figure 1 describes the following: (a) Department review, (b) Program review and (c) End Of Course Review (EOCR). Throughout this process the stakeholders of students, alumni, graduating seniors, and faculty are involved to address the appropriate ABET criteria. This process is not confined to a single program, but when appropriate, reaches out to assist other programs and departments for mutual benefits. A similar assessment system is presented by Pierrakos and Watson[4]. To be sure any plan involves the assessment of faculty effectiveness, teaching[5-6], and learning[7-9].

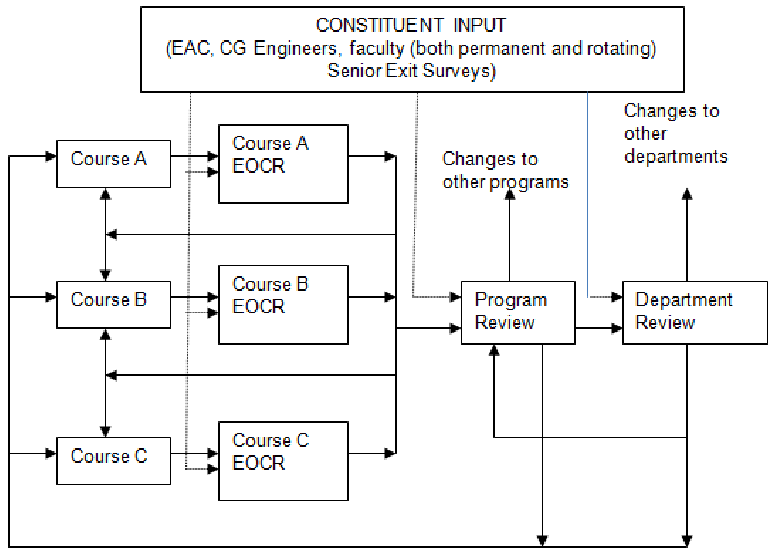


**Figure 1.** Electrical Engineering Assessment Process.

*B. The Challenge of High Faculty Turnover*

Maintaining a consistent assessment process in order to meet the ABET Criteria, as well as attaining student outcomes, maintaining course continuity and connectivity to other courses and programs can be especially problematic in programs that have high faculty turnover such as occurs at the USCGAs Electrical Engineering program where mandatory re-assignment and promotion of personnel creates an annual faculty turnover of about 10%. Note 60% of the program's instructors are permanent. While new instructors bring fresh perspectives into a program there is always the need to maintain some "institutional memory" with respect to its content, how it was taught, and how the outcomes were assessed. Consistency is especially important in programs where program changes are initiated by assessment results. This certainly doesn't necessarily imply that new faculty cannot change the course, but only that course modifications are done in an orderly process with the full knowledge of what occurred in the past so that previous mistakes are not repeated or the proverbial wheel is not reinvented. Whether or not there is high turnover, the EOCR creates a culture of assessment and expedites faculty "buy-in" into the assessment process.

*C. EOCR Solution*

To overcome the above challenges, as well as document continuous improvement we describe a relatively simple EOCR process. Our EOCR process is completed at least annually for every course. The end result is a document that describes the essential content of the course (i.e. syllabus, learning objectives, outcomes, projects, sample exams, sample notes, etc.), assessment data and rubrics, and recommended changes. This EOCR package can then be used to (a) give the next instructor a suitable starting point for when they teach the course, (b) provide assessment information for program reviews and curriculum revisions, (c) provide assessment data to serve as a reference point for when the next time the outcomes are assessed, and (d) provide necessary and objective information to the person writing the accreditation self-study document. This latter point is especially important since in the case of ABET accredited programs, the EOCR contributes to a well-documented story on how a program is meeting its assigned student outcomes and to what degree there is continuous improvement. The EOCR is especially valuable for curriculum reviews since changes to the particulars of a program are based on hard evidence as stated in the EOCR and not simply anecdotal stories.

Key aspects of the EOCR process include: the instructor and interested faculty that generate the EOCR document, and the assessment tools and corresponding rubrics. The latter is especially important in order to minimize instructor biases and outliers.

EOCRs are a significant part of the program's assessment plan and have been part of the USCGAs culture of assessment since at least 2000. The EOCR not only is a key element in a program's assessment plan, but is used to improve other aspects of the program not explicitly covered by the ABET criterion. The EOCR provides a formal means to assure quality control and improvement in our course offerings.

## EOCR Description

### *A. EOCR Process*

Initially, the Course Coordinator generates a draft document that fully describes all aspects of the course, followed by a meeting attended by all course instructors (if multi-section), other relevant stakeholders such as students as well as other instructors impacted by the course. Attendees include faculty members both inside and outside of the program. At the conclusion, the draft document is revised to reflect the input of the EOCR attendees.

### *B. EOCR Outline and Content*

The EOCR document provides the faculty a comprehensive snapshot of the course and includes the following:

1. Executive summary of course
2. List of EOCR attendees
3. Pending issues from the last EOCR
4. Summary of course changes in statement-resolution format
5. Course description including the objectives, a syllabus, a list of learning objectives, and a list of ABET a-k student outcomes, etc.

6. Course assessment instruments: homework, exams, quizzes, projects, as well as ABET a-k student outcome assessment tools

7. Assessment results including: course grades, test results, assessment averages (quizzes, exams, etc) and ABET a-k assessment results

8. Student surveys and instructor feedback from students

9. Rubrics used for ABET a-k student outcome assessment

10. Safety

11. Proposed course changes

12. Connectivity to other courses both in and out of the program

13. Appendix

    Where applicable or useful, the Appendix will have the following topics:

    a. Course syllabus

    b. Course description

    c. Learning objectives and applicable ABET a-k student outcomes

    d. Sample set of course notes

    e. Set of projects

*C. EOCR and assessment of student outcomes*

Each course has an assigned set of student outcomes which correspond to the ABET student outcomes a – k. Often these outcomes are amplified into what we call performance indicators (PIs). For example, outcome g, "An ability to communicate effectively" has two PIs that are separately assessed by the instructor. These PIs are (1) Prepare well-written reports, and (2) Present information orally to an audience." Figure 2 shows the process in which these PIs are evaluated. The specific assessment tools such as quiz, or test questions are called Barometric

Assignments (BAs). The process for evaluating student outcomes during the course review process is shown in Figure 2. Note the following: (a) The outcome assessment process is a significant part of the EOCR and drives the Program Review process, (b) outcome achievement is demonstrated if 70% of the students exceed the outcome score threshold of 75%. As readily observed, this process causes any course changes to be based on hard and consistent data, not anecdotal evidence.

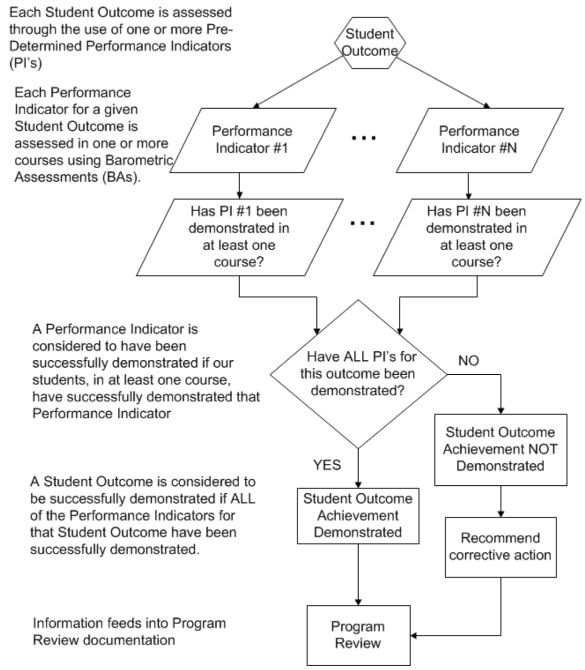


**Figure 2.** USCGA Student Outcome assessment process.

### *D. EOCR Cost and Benefits*

The EOCR is considered by the faculty to be a time consuming operation. However, the consensus is that this process serves to inculcate a culture of assessment into the program, and thereby provide for both program quality control and improvement, and a ready means of communication between faculty members. It is extremely helpful when the faculty member must plan on the next offering of the course, or hands it off to another instructor, particularly one who is inexperienced in that particular area. As Colella states[3], "The continuity and detailed reflections contained in the course review documentation provide the information necessary to keep the course and curriculum focused on program, departmental and institutional outcomes." Finally, the EOCR serves to document the attainment of student outcomes and provides the necessary information to provide for continuous improvement.

## Conclusions

In this paper we have presented a simple but elegant quality control and improvement process that is currently being used at the USCGA's Electrical Engineering Program where the faculty turnover is at an annual rate of 10%. The benefits of this process are as follows: (a) creates a culture of assessment, (b) provides a valuable means to ensure ABET Criterion #4 is achieved, (c) fosters communication between faculty within and outside a given program, and (d) provides orderly handoff during instructor transitions. The EOCR process has enabled the USCGA's Electrical Engineering program to successfully complete two ABET cycles.

## References


1 Crilly, P.B. and R. Hartnett. "Student Outcome Assessment and Course Continuity for Programs with Moderate Faculty Turnover," *Proceedings of the ASEE Conference*, Seattle, WA, June 2015.

2 ABET Board of Director. *Criteria For Accrediting Engineering Programs.* Publication. Baltimore: ABET 2014-2015.

3 Colella, Kurt. 2002. "The Implementation of an Effective System of Assessment in the Engineering Department at the United States Coast Guard Academy," *Proceedings of the ASEE/IEEE Frontiers in Education Conference*, Boston, MA November 6-9, 2002.

4 Pierrakos, Olga, and Heather Wilson. 2013. "A Comphrehensive ABET-focused Assessment Plan Designed to Involve All Program Faculty." *Proceedings of the 2013 IEEE Frontiers in Education Conference*, Oklahoma City, OK, October 23-26, 2013.

5 Marathe, Ashutosh. 2013. "Assessment of Engineering Faculty Peformance I the Devleoping Academically Autonomous Environment – VIT, Pune, India – A Case Study." *Proceedings of the 2013 IEEE Frontiers in Education Conference*, Oklahoma City, OK, October 23-26, 2013.

6 Brent, Rebecca and Richard M. Felder. 2004. "A Protocol For Peer Review of Teaching," *Proceedings of the 2004 Society of Engineering Education Annual Conference & Exposition*, Salt Lake City, UT, 2004.

7 Serra-Toro, V. Javier Traver, and Juan-Carlos Amengual. 2014. "Promoting Commitment and Responsibility Through Self- and Peer-assessment," *Proceedings of the 2014 IEEE Frontiers in Education Conference*, Madrid, Spain, October 22-25, 2014.

8 Ashour, Omar, M., Shraddha Sangelkar, Russell L. Warley, and Oladipo Onipede. 2014. "Redesign the Engineering Teaching and Assessment Methods to Provide More Information to Improve Students' Learning," *Proceedings of the 2014 IEEE Frontiers in Education Conference*, Madrid, Spain, October 22-25, 2014.

9 Gonzalez de Sande, and Adarsh Murthy. 2014. "Including Peer and Self-Assessment in a Continuous Assessment Scheme in Electrical and Electronics Engineering Courses," *Proceedings of the 2014 IEEE Frontiers in Education Conference*, Madrid, Spain, October 22-25, 2014.


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# How to Make Our Syllabus More Effective to Student's Learning Experience

***By Md. M. Rashid, P.E.[1], and Mahbub Ahmed[2]***

## Abstract

Syllabus provides basic course related information to students, and creates a first impression about an instructor and his or her attitudes toward teaching. A syllabus is seen as an agreement that serves as a "virtual handshake" between an instructor and students regarding mutual rights and responsibilities. Research indicates that a traditional syllabus contains checklists of items that provide basic information such as course goals, course requirements, grading, schedule and so on. The existing literature contains many of these checklists, and numerous articles have been published. This work examines these checklists and lists the most important ones. Examples are provided with these checklist items. The main purpose of this work is to identify factors that make a syllabus more effective to student's learning experience. A traditional syllabus can be enhanced by describing it in a warm and friendly tone, clarifying relationship among course goals and assignments, and by specifying rationale of assignments, to name a few. Examples of how and why these factors can make a syllabus more effective are discussed.

**Key words:** Traditional syllabus, teaching effectiveness, checklists, best practices, and friendly tone

## 1.0 Introduction

Syllabi are a ubiquitous part of the teaching process, and most colleges require faculty to share them with their students. Syllabus informs students about a course and its requirements, and creates a first impression about the instructor and his or her attitudes toward teaching. A syllabus presents a cognitive map of course goals; communicates procedures, rules, expectations, grading scheme; and serves as a contract between students and the instructor. A well designed syllabus clarifies the relationship between course goals and assignments. Syllabi can play an important role in engaging students and creating an effective classroom atmosphere.

Syllabi differ widely in style and design – some are long and detailed, while some are brief and short. In most cases, however, they share certain basic components. For example, most syllabi describe ways to contact the professor, means for meeting course goals, and a schedule of events, and so on. In addition to these basic components, a detailed syllabus also includes prerequisites for the course, disclaimers, and a bibliography of required readings. In order to fulfill its motivational function, a syllabus also may include rationales for course objectives and assignments.

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In describing effectiveness of a syllabus, the current literature uses terms such as "strong syllabus", "well-designed syllabus", "well-constructed syllabus", "effective syllabus" or "incomplete or poorly-designed syllabus".

This work reviews existing literature and summarizes the basic information that a traditional syllabus should contain. This work examines syllabus checklists and lists the most important ones. The main purpose of this work is to identify factors that make a syllabus more effective to student's learning experience. A traditional syllabus can be enhanced by describing it in a warm and friendly tone, clarifying relationship among course goals and assignments, and by specifying rationale of assignments, to name a few. Examples of how and why these factors can make a syllabus more effective are also discussed.

## 2.0 Previous Study

A number of papers have been published focusing on different aspects of syllabus. Numerous articles are also available on internet sites of education instructions that provide templates, tips and guidelines on how to write a "good" syllabus. These publications generally focuses on, (i) general purpose of the syllabus, and (ii) checklists and best practices that should be included in a traditional syllabus. Research journal papers focusing on how to develop effective syllabus have also been published.

**2.1 General purpose of syllabus**: A syllabus is a students' "first impression" of a course, which resonates through the semester. It can give students an immediate sense of what the course will be about, what they will learn, and how they will be evaluated.

At the beginning of a semester students often visit multiple classes to decide which course (s) or instructor is the most exciting, and best fit their schedule and learning style. Thus, a syllabus may work as a vehicle to excite students and convince them to take a particular course. Study indicates that through reading the syllabus students are able to acknowledge instructor's passion for the subject, and his or her teaching philosophy. Littlefield (1999)[2] suggested that a syllabus serves several purposes, it sets the tone for a course, motivates students to achieve course goals, and serves as a planning tool for faculty, to name a few.

In addition to being a cognitive map, syllabi can serve many purposes. A review of the current literature revealed that a syllabus can serve as a: (i) communication mechanism, (ii) a planning tool for instructor (iii) a course plan for students, (iv) a pedagogical resource tool for student learning, (v) an artifact for teaching evaluations of an instructor, and (vi) a contract of policies and procedures between instructor and student. Instructors tend to rate each purpose differently (Fink, 2012)[1].

Harnish and Bridges (2011)[3] investigated whether the tone of a syllabus depicts instructor's attitude towards teaching. An experiment was conducted in which the course syllabus was manipulated to reflect a friendly or an unfriendly tone so that student's perceptions about the instructor could be explored. Results supported the hypothesis that a syllabus written in a friendly, rather than unfriendly, tone evoked perceptions of the instructor being more warm, more approachable, and more motivated to teach the course.

**2.2 Checklist and best practices for a traditional syllabus:** The following section describes basic items that a traditional syllabus might contain in order to assist students understand mutual expectations. Including each item in the list may not be necessary; however, they should be used as a guide. This is not an exhaustive list and some syllabi will typically contain only portions of all the items listed here (Johnon, 2006)[4].

**A. General course information**:

- Name of course – should match with institution catalog (i.e., CVEEN XXXX - Engineering Statistics)
- Term/quarter/semester, and its duration (i.e., Fall 2015; January 21 to May 18)
- Location – where course/lab will be held (i.e., 217 John Doe Hall - class, and John Doe Lab – for laboratory work). Website or other electronic locations for the course (i.e., Blackboard) may be listed here.
- Units/time dedicated per week (i.e., meets on T, Th at 4:00 – 5:15 PM)
- Prerequisites/co-requisites – should include course names and numbers according to institution catalog so that they can be easily identified.

**B. Instructor information**

- Instructors' names and preferred name – name or names and their function in relation to the course, along with degrees and credentials (i.e., Dr. John Doe, P.E., instructor; and Smith, L., Ph.D candidate, teaching assistant (TA)). The instructor prefer to be called Professor Doe, and the TA prefer to be called Mr. Smith)
- Office hour – indicate where and how students should communicate with faculty and/or TA, how students make appointments i.e., drop in, phone, sign up, or e-mail) (i.e., 215 Green Hall; M, W, TR at 1:00 – 2;00 PM for instructor; and 215 White Hall; M, W, TR at 10:00 – 11:00 AM for TA
- Contact information (instructor): Phone: [xxx]-xxx-xxxx (office) or [xxx]-xxx-xxxx (home) – emergency only or E-mail:John.Doe@gooduniveristy.edu
- Contact information (TA): Phone: [xxx]-xxx-xxxx (office) or [xxx]-xxx-xxxx (home) – emergency only or E-mail:Smith.Wu@gooduniveristy.edu

**C. Purpose of the course**

- Course purpose - clearly describe the course contents and what the learner may expect to learn. Including the catalog description as it appears in the most recent course catalog works well.
- Course goals – broad, general statements that establish the direction of the course. Couse goals are not generally measureable. They should be clearly linked to program goals. For example, a goal of an Engineering Statistics course can be described as: *"Equip the student with skills in probability and statistics so that they are prepared to apply these skills in civil engineering coursework and build upon these skills through further study in probability and statistics."*
- Course objectives – more specific than goals and address achievable, measurable skills, knowledge, and attitudes that students will need to acquire. Course objective may be further broken down into lesson, module, or unit objectives. The objectives of aforementioned goals of the Engineering Statistics course can be described as: *(i) classify data by various methods, (ii) pictorially represent data through a variety of graphs, (iii) compute measures of central tendency, (iv) calculate measures of dispersion, (v) define a set, a sample space, and an event, and (vi) construct and use Venn diagrams, and so on.*

**D. The learning environment**

- Required texts - list the required text (s) title, author (s), publisher (s), and edition (i.e., 2nd Ed.), and picture of the cover page. If textbooks are not required, clearly state so.
- Required materials – list materials that each student must obtain (i.e., engineering paper, straight edge, flash drive, and scientific calculator, etc.)
- Provided materials - list materials that instructor will provide in class (i.e., lecture notes), during exams (i.e., interest tables) and with request (i.e., copy of reference text or student study guide)
- Recommended resources – list resources that student will find helpful in learning, but are not required (i.e., reference text, online sites, youtube link)

**E. Time schedule/course plan**

- Schedule/course plan – provide course calendar indicating which materials are covered and when. The schedules can be organized by week and by topic or may be arranged as modules, depending on the course and program.
- Lecture and/or lab topics - describe the topic or theme of the lectures/labs. Topics may be subcategorized by lecture hour or by week. Topic should be descriptive enough so that students may best prepare for in-class time.
- Events, assessments, and due dates: The schedule should include all assessments for lecture/lab; due dates for projects, special projects, and presentations. Also, include dates that are holidays, days in which classes will not be held due to instructor’s absence or due to other reasons.

**F. How learning will be assessed**

- Grading procedure – this generally include in-class (i.e., exams and quizzes) and out-of-class assignments, multiple-choice exams, essays, oral reports, group projects, and so forth. This may also include self assessments, and peer assessments.
- Grading scale and method – indicate how grades are calculated. Grades should normally be in compliance with the college policy or catalog (i.e., A, B, C, D, F, etc.). Also, list any other information relevant to grading, such as if extra credit will or will not be offered.
- Policy on missed assessments – describe consequences for missing or being late to an assessment. Indicate if the score will be dropped or will the missed assessment can be re-submitted. If students are allowed to make up missed exams/assessments, explain within what time frame students are allowed to make up an exam.
- Grade posting - include how often and where (i.e., bulletin board or a website) assessments scores will be given to the student and how this information can be accessed.
- Results of a failing grade - syllabi should include information to advise unsuccessful students (i.e., students who is not doing well or who might fail) the course how to access student support services or tutoring services.

| G. Technical, classroom, and college policy information |
|---|
| • Syllabus amendments – some point during the semester the instructor might feel that there is a need to alter the plan after the syllabus has already been distributed. Therefore, it is helpful to have a statement included in the syllabus to inform students that the syllabus is subject to change. A general statement may be included, such as, *"The information in this syllabus is subject to change in extenuating circumstances."*<br>• Special needs - information specific to the course that relates to students with special learning needs or disabilities, physical handicaps, or religious obligations may be included (i.e., students with hearing deficits or learning disability may need special accommodation). The syllabus should indicate that students contact the primary instructor within the first week of the course for accommodation).<br>• Last course revision date – include the date of last revision of the syllabus helps the instructor to track how often the course is updated and make sure the students have the most up-to-date version of the syllabus.<br>• Student conduct and class/college policies - specific policies for the class (i.e., cell phone and laptop usage in class) that are consistent with the most recent department/college policy should be listed. Additionally, specific classroom policies in regard to academic honesty, attendance, tardiness, class participation, and how attendance affects grades should be included. |

## 3.0 Guidelines to Make a Syllabus More Effective

**3.1 Provide a detailed syllabus**: A syllabus with sufficient details is considered to be a strong or detailed syllabus with compared to a brief syllabus.  A brief syllabus is generally a two-page document, which includes general course related information such as the instructor's name, course objectives, number of exams to be taken, assignment due dates, and a brief statement of course policies. A detailed syllabus includes the same general course information but also includes four or more pages of additional information on course objectives, course policies, assignment deadlines and expectations from students. This additional information may convey an instructor's standards of professionalism and may increase perceptions of instructor's support and enthusiasm about course material (Jenkins et. al. 2014)[6]**.** A detailed syllabus can educate students about the course and institution resources, and thereby reduces student anxieties. Therefore, a course with detailed syllabus can run a course more smoothly.

Recent research also suggests that an instructor with more detailed course syllabus is perceived to be more effective and competent by students. Jenkins et. al. (2014)[6] and Saville et. al., (2010)[5] studied how students perceive a brief vs. detailed version of a syllabus through surveys. In these surveys, students were asked to rate their instructors in terms of teaching quality. Instructors with detailed syllabus were ranked higher than their peers and received stronger recommendation.

Studies by Buskist et al. (2002)[7] and Saville et. al., (2010)[5] indicates that instructor with detailed syllabus are also perceived as being approachable, caring, and flexible - interpersonal characteristics that students tend to associate with exceptional teaching quality**.** Additionally, students viewed the instructor with detailed syllabus as being more prepared, cognizant of current information, and encouraging critical thinking.

Although it is certainly possible that some students might not read a more detailed syllabus, the benefits of having such a syllabus is likely to outweigh the costs.  A detailed syllabus has high potential to foster positive attitudes toward an instructor, thus have the greatest impact on their students (Saville et. al., (2010)[5].

**3.2 Make it complete – but not too long:** In general, we should strive to include constructive details in our syllabus without vagueness. However, we should not overwhelm our students with a flood of information. For example, a 10 to 15-page syllabus will create anxieties among students and they may not read such a long syllabus. We should not include the details of assignment descriptions, rubrics, and course project in the syllabus – we should provide them with appropriate assignments.

As an alternative to a long syllabus, instructor can develop both a short version and a long version of the syllabus. The long version can be made available to students electronically (i.e., posting at course Blackboard or course website), while short version can be provided hard copy format.

**3.3 Develop syllabus with proper organization**: A syllabus should provide information in an organized way, and should be easy to navigate. A syllabus for a popular course could be ineffective because of weak or ineffective organization. This is particularly important for web syllabi that often contain a wealth of information. In an organized syllabus, student can locate information with minimum effort. Syllabus pages that would contain narrative can be organized in sections with bold headings, bulleted lists, and succinct tables (Parkes and Harris, 2002)[8]. An incomplete or poorly-designed syllabus impedes communication between faculty and students, increases student anxiety and potential complaints, and could potentially reduce overall teaching effectiveness **(**Abdous, and Wu, 2008)[9]. McKeachie (2002)[10] suggested that a less organized syllabus might signal to students that their teacher does not care about them. Blowers (2002)[11] also reported that syllabus with clear guidelines alleviates student anxiety and demonstrates instructor's cares for the course.

**3.4 Develop syllabus with user friendly tone**: The tone of the syllabus can indicate how approachable an instructor is, and students often form an immediate impression of whether they will like the instructor and his or her course just from reading the syllabus. Positive or friendly language should be used throughout the syllabus, as this proves "welcoming" feeling to the students about the instructor and the course. For example, note the difference in tone (Table 1) in the two examples of office hours, with the warm version indicating, *"Individual assistance is always available by appointment. I look forward to seeing you during student hours."* The content in Table 1 has been adapted from Harrish et al. (www.psychologicalscience.org)[12] Examples of cold and warm tone for different syllabus sections are also provided in Table 1 below.

**Table 1 – Examples of cold and warm tone in syllabus section**

| | |
|---|---|
| | **Syllabus section – Office Hours** |
| Cold tone | • Office Hours: CEE 14.203 T & TR 1:00 – 2:00 PM**,** md_rashid@uml.edu<br>• If you need to contact me, you may email me or contact the CEE department and leave a message. I will return your call. |
| Warm tone | • Student Hours: CEE 14.470 T & TR 1:00 – 2:00 PM**,** md_rashid@uml.edu<br>• Individual assistance is always available by appointment. I look forward to seeing you during student hours. Please stop by. |
| | **Syllabus section – Instructor's teaching philosophy and beliefs** |
| Cold tone | • Think that this course is a bit like a restaurant. You order and pay for the food, and I serve it. I cannot and will not make you eat it - that is your choice. To assist you in understanding the prominent ideas, theories and principles in testing and measurement, I will assign tasks for you to complete. . . |
| Warm tone | • I would like you to take a moment, and think back to the first time you ordered something off the menu at a restaurant when you were out with your family. This course is a bit like that – ordering something off a menu at a restaurant. You selected this course off of a menu of courses and certainly, I don't have to tell you the price you paid for your "meal." My job is like the chef in the restaurant. I want to serve you the most appetizing and nutritious food I can. But unlike that meal with your family, I will not hound you if you are not hungry. Why? Well, from my experiences with my own kids, I know I cannot make you eat what I prepare. That is your choice. But I hope that you come to this class hungry. I will present ideas, theories, principles and solve problems that I+ have developed over several years. To assist you in learning the course material, I will assign home works, projects and give exams and quizzes for you to complete. . . |
| | **Syllabus section – Methods of instruction and course delivery** |
| Cold tone | • For each lecture session, there is required reading. Lecture note will be distributed. The lecture is intended to amplify, explain and demonstrate the material in the textbook and lecture notes. |
| Warm tone | • You might ask why optional reading? I have developed the optional reading lists for a number of reasons. Foremost, the readings provide an opportunity for those interested in advanced engineering mechanics to go beyond the material provided in the required text and examine in more detail specific topics that are of interest to structural mechanics. Second, too often students simply accept what they see in a text as truth without critically evaluating the information. My hope is that you will start (if you haven't already) being critical of what you are reading and learning. I have carefully selected the optional readings because they are provocative and provide a different perspective to the required text. The optional reading has been placed on the blackboard for the class. |

**Table 1 – Examples of cold and warm tone in syllabus section, continued..**

| | |
|---|---|
| **Syllabus section – Methods of instruction and course delivery** | |
| Cold tone | • For each major topic, lecture notes will be provided. The lecture note is intended to amplify, explain and demonstrate the material in the textbook |
| Warm tone | • How can you best succeed in this course? Engage in active reading of the course lecture notes and the assigned text. The purpose of the lectures note is to amplify, explain, and demonstrate the material presented in the text. There will be some overlap between the text and the lecture notes, but there will be a substantial amount of material that is unique to each. Your understanding of each lecture will be best if you have read the note before the lecture. |
| **Syllabus section – Attendance** | |
| Cold tone | • I will keep attendance records and report absences throughout the term. Any student failing to attend class for two consecutive weeks, without an approved excuse from their instructor, will be administratively withdrawn and notified via email that you have been withdrawn and a grade of "W" will be recorded. |
| Warm tone | • You should try your best to attend every class. I understand that extenuating circumstances might arise, and you might not attend class. But please let me know before class if you cannot attend. If circumstances make you miss more than fou classes during the semester, you may have overextended yourself. In this case, I would suggest you to consider dropping the class. |
| **Syllabus section – Participation** | |
| Cold tone | • Active participations from each student are expected in this course. I expect you to actively participate by helping to summarize key learnings from the lecture and class discussion. Your comments, thoughts, questions and engagement in the in-class demonstrations may influence your final grade. Please be advised that I may call on students or make comments that are intended to make the lectures a little more lively and interesting. |
| Warm tone | • My experience indicates that the active participation is the best way to engage in learning the material. I hope you actively participate in this course. Your participation will make the lectures more fun, more lively and interesting. I welcome your comments, thoughts, questions, and hope you take an active role in the in-class demonstrations. If the class is too quiet, I may call on a student to share his or her thoughts. Please note that if I do so, I am not "picking" on that student. |
| **Syllabus section – Missed exams** | |
| Cold tone | • No make-up exams will be allowed without documentation of illness, death in the family or other suitably traumatic event. |
| Warm tone | • Illnesses, death in the family or other traumatic events unfortunately are part of life. A make-up exam will be given if you contact me within 24 hours of the events and provide proper documentation. |

**Table 1 – Examples of cold and warm tone in syllabus section, continued..**

| | |
|---|---|
| | **Syllabus section – Grading** |
| Cold tone | • The grading scheme is provided in the syllabus. Three exams account for 65% of your course grades. Exams are designed to assess your understanding of core concepts covered in lecture, discussion, homework and the assigned readings. |
| Warm tone | • The grading scheme is provided in the syllabus. Three exams account for 65% of your course grades. Exams are designed to assess your understanding of core concepts covered in lecture, discussion, homework and the assigned readings. Exams would take approximately 60 minutes to complete, but please take your time and remember that you have the full class meeting time (75 minutes). I usually allow additional five minutes to allow you to revisit your work. |
| | **Syllabus section – Learning resources for student** |
| Cold tone | • If you need help with the course, please see me during office hours. If you cannot make office hours, please send me an e-mail or contact me to set up appointment. |
| Warm tone | • I understand the fact that we all need assistance in something at different points in our lives. If you find yourself not understanding the assigned readings, lectures and/or homework assignments, please set up an appointment with me. You can drop by during my office hours or arrange a mutually convenient time if you can't make my office hours. You can also send an e-mail to set up an appointment with me. |

The most effective syllabi are the one that use a friendly and positive tone. This type of syllabus is better remembered by students. Study indicates that a "warm instructor" is seen as more effective teacher and a pleasant person to take class from (Harnish and Bridges, 2011)[3].

A friendly syllabus presents course requirements in a manner that suggests that faculty and students will work well together. A friendly syllabus does not use condescending language and provides course and institution related information (i.e., last day to withdraw from course) that all students may not have.

Study also indicates that students find it welcoming if instructor provides personal information such as home phone number and permissible times to call. This may seem a bit risky, but only a few students may call, and all will appreciate this gesture. Other personal information such as what the instructor wants to be called by will make him or her more human. If instructor's teaching methods are unusual or he or she speaks the language with an accent, they should be explained in the syllabus.

**3.5 Develop your syllabus with consistent tone:** The consistency is the key for a syllabus to be effective. The tone and proposed process articulated in the syllabus should match. For example, professors who expect to take an expert role should clearly communicate this in their syllabi, just as those who adopt a more student-centered approach should communicate this (Baecker 1998)[16].

**3.6 Describe rationale of the course:** An effective syllabus describes its rationale – it discusses why this course satisfies departmental or institutional requirements and how it fits into students major, or why it is a valuable elective or why it is important for their career. It should answer the following questions to the reader. Why does this course exist? What is the content? Why should students take this course and how will it contribute to students overall educational experience? Is the course a prerequisite for more advanced courses? How would you define the course (e.g. introductory, intermediate, or capstone level)? How student can benefit from the knowledge and skills acquired from this course?

Instructor should not assume that all students know the answer to these questions. If the syllabus does not clearly state the purpose and value of the course, students may believe the main purpose of taking it is simply to fulfill a “poorly understood’ curricular requirement.

As example, the “rationale statement” for Engineering Economics course can be describes as:

*Engineering Economics is a 3-credit required undergraduate course for Civil and Environmental Engineering degree program. This course provides an understanding of economics principle needed for management of engineering project. This course is designed to present the major concepts, tools and techniques of economic analysis so that students are able to evaluate projects and select economically sound alternative. The major emphasis of this course is on the analysis and application of time value of money and its impact on decision making. This course will also provide all students with a sophisticated comprehension of the benefit-cost concepts, inflation and depreciation analysis and microeconomic principles applicable to engineering and planning projects.*

**3.7 Describe course assignment:** Study shows that faculty generally does not describe their assignments in the syllabi. For example, Littlefield (1999)[2] reported that only 50% syllabus described course projects, 25% described papers, and 18% described tests. Slattery and Carlson (2005)[14] indicated that syllabus should include at least brief description t of assignments and their due date. The more description of the assignment can be shared in other ways, i.e., using class discussion and additional handout.

**3.8 Develop learning outcome statement using action word.** The learning outcomes statements have three major defining characteristics, (i) they specify an action by the students that is observable, (ii) they specify an action by the students that is measurable, and (iii) they specify an action that is done by the students (rather than by the faculty member). They are specific to the course, are student-centered and are assessable. To make learning outcome statement more effective, instructor should use concrete, action verbs. Examples of action verbs are provided in the Table 2 below. The content in Table 2 has been adapted from an internet link of University of Florida (<http://assessment.aa.ufl.edu/slo-table-3>)[15].

**Table 2. Verbs for Bloom’s Taxonomy**

| Remember | Understand | Apply | Analyze | Evaluate | Create |
|---|---|---|---|---|---|
| Arrange | Classify | Calculate | Combine | Appraise | Arrange |
| Define | Describe | Construct | Figure | Argue | Assemble |
| Locate | Identify | Classify | Find | Assess | Compose |
| Recall | Indicate | Estimate | Sketch | Defend | Create |

It is recommended that learning outcomes statements start with the phrase, "*The student will…*". Example of learning outcome statement for Engineering Mechanics – Statics course is described below:

*"The student will be able to: (a) draw free body diagram, (b) apply equations of equilibrium to obtain values of unknown forces and reactions, (c) calculate position, force, and moment vectors in 3-dimension, (d) calculate moment of a force using vector analysis and (e) assess whether a given structure is structurally determinate or indeterminate."*

**3.9 Provide course schedule:** Syllabus should include tentative schedule of exams, reading assignments, homework and project due dates. The word "tentative" allows the instructor to change if necessary. Study shows that schedule is very important to students as they can use it to prepare for exams and completing their assignments (Becker and Calhoon, 1999)[13]. Therefore, omitting schedule may have serious implications for students' abilities to plan and learn during the semester. Based on Littlefield (1999)[2] research, faculty omits project due dates (42%) and exam dates (65%). In scheduling reading assignments from textbook, faculty should specify chapter, page number along with eye catching phrase, i.e., *Two Dimensional Truss Analysis*. With rising textbooks cost, students are finding other ways to complete reading assignments, including reading texts with similar material or a previous edition of the current text. When reading assignments are not from a text, a complete reference list should be provided. The schedule section of the syllabus should also indicate where these readings can be found (i.e., reserve in the library, purchased from the bookstore, on the Internet, or PDF files linked to the Web syllabus, and so on) (Slattery and Carlson, 2005)[14]

**3.10 Include teaching philosophy and teaching approach:** Syllabus should briefly describe instructor's teaching approach and teaching philosophy. This inclusion serves two purposes – (i) this allows student adjusting their learning style and (ii) this allows student to decide at the early of the semester whether they should take course from this instructor or not. Study indicates that a well-articulated teaching philosophy is an indicator of instructor's passion for teaching.

**3.11 Allow students to provide course input**: Syllabus should describe whether opportunities exist to provide instructor with regular input on how students are experiencing the course throughout the semester. This will send a welcoming signal to students and they will feel that instructor cares for them.

**3.12 Provide grade tracking technology**: Study indicates that an increasing number of faculty member include a means (i.e., through Blackboard or other Web-posted grading systems) by which students can track their grades electronically. Students seem to appreciate this opportunity (Slattery and Carlson, 2005)[14]

**3.13 Provide grade determination criteria and rubric**: Syllabus should describe how final grade are weighted and calculated. The grading criteria and rubrics used to guide the determination of these grades should be included. A transparent breakdown of how different assignments are weighted and translated into grades should be provided. It should be made clear whether instructor will use percentages, a point-based system, or a weighted system to calculate grade. Additionally instructor's policy for grade disputes or rewrites should be included. Slattery and Carlson (2005)[14] suggests that providing and adhering to a grading rubric can prevent students from perceiving grades as unfair. A statistics of past grading records for this course can also be added in this section. This will allow students to feel what they can expect to get in the class.

**3.14 Describe students expectation from instructor:** Study shows that most faculty list expectation i.e., attendance, due dates, and academic honesty from students in their syllabus, but few lists what students could expect from faculty for violation of his or her policy (Littlefield, 1999[2]; and Slattery and Carlson, 2005[14]). Syllabus should describe consequences for violating these expectations.

**3.15 Include statement about observance of religious holidays.** Syllabus should describe policy statement about observation of religious holy days. A student who is absent due to observance of a religious holy day should be allowed to take an exam or complete an assignment. These can be scheduled within a reasonable time after the absence, through consultation with the student.

**3.16 Describe policy regarding students with disabilities:** A policy statement regarding accommodating students with disabilities should be described in the syllabus. The policy statement can be described in welcoming manner as follows: *"In compliance with the University policy and equal access laws, I am available to discuss appropriate academic accommodations that may be required for student with disabilities."* Requests for academic accommodations should be made during the first three weeks of the semester with proper documentations, so arrangements can be made. Students are encouraged to register with Student Disability Services to verify their eligibility for appropriate accommodations.

**3.17 Provide inclusivity statement:** Students may come from a variety of ethnic and cultural backgrounds and perspectives. To welcome all students in the course, syllabus should include inclusivity statement. An example of such a statement is provided below:

*"The civil and environmental engineering (CEE) department is committed to providing an atmosphere for learning that respects diversity. As a faculty member of CEE, I am fully committed to diversity and to making decisions without regard to race, creed, religion, national origin and other factors. I am commited to equitable treatment and non-discriminatory policies."*

**3.18 Consider including a formal code of conduct for your students to sign**. A formal commitment from the students about conducts during class fosters mutual understanding and respect between the students and instructor. As electronic technology such as cell phone and laptop computer has become widely available, chances of their misuse during a class is also increased. Syllabus should include strict policy concerning texting, emailing, and other disruptive activities. The possible consequences i.e., losing class participation for violating the policy should be made clear.

**3.19 Provide information of available resources and support services.** List of available resources and support services in the campus should be provided. A list of additional information that can be added in a syllabus is provided below:

- Helpful hints on how to study, take notes or do well in class
- Glossary of technical terms used in the course
- Calendar of campus lectures, plays, events, exhibits, or other activities of relevance to your course
- References on specific topics for more in-depth exploration
- Bibliography of supplemental readings
- Location of tutoring center, advising office for international students, etc.
- Location of counseling center and campus health clinic
- How to get assistance regarding software use in the campus

**3.20 Provide incentive to read the whole syllabus.** Students are likely to read the syllabus more carefully if they are given incentive. Therefore, provide extra points or make it part of first assignment, to ensure they read it. Make them sign a statement that they have read the syllabus and concur with the rules and regulations described in it.

**3.21 Revisit your syllabus to continuously improve:** A good first step to improving a syllabus is to share it with colleagues for feedback. Students who have previously taken the course might also be able to identify what was effective or confusing in the syllabus.

## 4.0 Summary and Conclusions

Syllabus makes the first impression to students about an instructor or a course. Therefore, efforts should be made to provide a syllabus that will promote effective learning experience for students.

The actual learning experiences that students have in their classrooms are likely to have the greatest effect on their perceptions of teaching effectiveness. An instructor's teaching effectiveness depends on many factors – such as instructor's knowledge, teaching style and interpersonal skills, and enthusiasm for the subject matter to name a few. But providing students with a more detailed and organized syllabus might be a simple way to foster positive attitudes toward an instructor compared to his or her peers. A good syllabus provides a context by which instructor can have the greatest impact on their students.

In addition to provide basic information, a syllabus will be more effective if it is well-written, organized, and detailed and articulated in a "friendly" and "welcoming" manner. This work provides many useful "best practices" to make a syllabus more effective. These best practices have been published in various publications. The authors provided useful insights and examples of how these practices can be articulated and implemented.

This work validates the hypothesis that there are factors that makes a syllabus more effective and that an effective syllabus plays an important role in student's learning process. Instructors with detailed and organized syllabus are ranked higher by students. However, this hypothesis is only true when teaching "ability" and teaching "skill" of an instructor with "effective syllabus" is equivalent to his or her peers. Therefore, an instructor with poor teaching skill may not be ranked higher by students even he or she provides an effective syllabus.

## 5.0 References


1. Fink, B. Susan, (2012). “The Many Purposes of Course Syllabi”, *Syllabus*, 1 (1)
2. Littlefield, V. M. (1999). “My syllabus? It’s fine. Why do you ask? Or the syllabus: A tool for improving teaching and learning.” Paper presented at the *Society for Teaching and Learning in Higher Education*, Calgary, Canada
3. Harnish, J. Richard and Bridges, K. Robert (2011), *Social Psychology of Education*, 14 (3), 319-330
4. Johnson, C. (2006). Best Practices in Syllabus Writing Contents of a Learner-Centered Syllabus, *The Journal of Chiropractic Education*, 20 (2), 139-144
5. Saville, K. Bryan, Zinn, E. Tracy, Brown, R. Allison, and Marchuk, A. Kimberly (2010). “Syllabus Detail and Students’ Perceptions of Teacher Effectiveness”, *Teaching of Psychology*, 37, 186–189
6. Jenkins, S. Jade., Bugeja D, Ashley, and Barber, K. Larissa (2014). “More Content or More Policy? A Closer Look at Syllabus Detail, Instructor Gender, and Perceptions of Instructor Effectiveness”, *College Teaching*, 62, 129–135
7. Buskist, W., Sikorski, J., Buckley, T., and Saville, B. K. (2002). “Elements of master teaching. In S. F. Davis & W. Buskist (Eds.)”, *The teaching of psychology: Essays in honor of Wilbert J. McKeachie and Charles L. Brewer*, Mahwah, NJ, Lawrence Erlbaum Associates, 27-39.
8. Parkes, J., and Harris, M. B. (2002). The purposes of a syllabus. *College Teaching*, 50 (2), 55-61.
9. Abdous, M'hammedm and Wu, He (2008). “A Design Framework for Syllabus Generator”, *Journal of Interactive Learning Research*, 19 (4), 541-550.
10. McKeachie, W. J. (2002). McKeachie’s teaching tips: Strategies, research, and theory for college and university teachers (11th ed.). Boston: Houghton Mifflin.
11. Paul Blowers, P. (2002). “Course Syllabus Construction: A Stitch in Time Saves Nine”, *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*, American Society for Engineering Education
12. Harnish, J. Richard., McElwee, R, O’Brien, Slattery, M. Jeanne, Frantz, Sue, Haney, R. Michelle, Cecilia, M Haney, and Penley, J. Shore, “Creating the Foundation for a Warm Classroom Climate Best Practices in Syllabus Tone” <http://www.psychologicalscience.org /index.php/publications/observer/2011/january-11/creating-the-foundation-for-a-warm-classroom-climate.html>, accessed on March 22, 2015
13. Becker, A. H., and S. K. Calhoon (1999). What introductory psychology students attend to on a course syllabus. *Teaching of Psychology*, 26, 6–11.
14. Slattery, M. Jeanne and Carlson, F. Janet, (2005). Preparing an Effective Syllabus Current Best Practices, *College Teaching*, 53 (4), 159-164.
15. University of Florida, “Institutional Assessment, Student Learning Outcomes” http://assessment.aa.ufl.edu/slo-table-3, accessed on March 22, 2015
16. Baecker, D. (1998). Uncovering the rhetoric of the syllabus. *College Teaching*, 46 (2), 58–62.


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# Teaching an Undergraduate Electromagnetics and Antennas Course Using A Hand-Held RF Analyzer - Engaged Learning

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## Abstract

This paper describes an experiential learning concept to teach undergraduate electromagnetics and antenna theory using a hand-held RF analyzer and other basic laboratory apparatus. The analyzer contains both an RF source and spectrum analyzer. The RF source serves to enable SWR measurement for stub matching, measuring cable losses, detecting cable faults, cable lengths, and such tasks such as verifying that the half wave dipole has nearly unity SWR at both its fundamental frequency and its odd harmonics. The spectrum analyzer portion of the RF analyzer allows for efficient measurement of radiation patterns for various types of antennas and thus students can design and quickly test several different types of antennas. The increased efficiency enables increased depth and breadth of antenna topics.

## Keywords

Antennas, laboratory practice, engaged learning

## Introduction

The capabilities of the current generation of modern portable RF analyzers can greatly enhance the laboratory experience for an undergraduate electromagnetics (EM) and antennas course. The increased efficiency brought about by these modern portable analyzers allows for additional experiments that in the past, due to time constraints were not feasible. Particularly noteworthy is the ability for the student to get "quick turnaround" on their design in order to verify that their design has minimal SWR and the desired radiation pattern. This paper builds on previous work described in reference[1-2] that seeks to make conventional EM courses more relevant, engaging and "more fun" to the current generation of electrical engineering students. In this paper, we use the Agilent 9912A RF analyzer, but there are many other excellent portable analyzers available from such companies as Rohde & Schwarz, and LeCroy. This paper seeks the answer to the question often posed by undergraduate electrical engineering students, "Now that we have this wonderful EM theory, what can we do with it?"

We first will present some basic background sources that address current instruction and laboratory practices, and then discuss specific experiments on how a portable RF analyzer can be used to enhance the laboratory experience for an antennas course.

Selvan[2] addresses student centered EM instruction; Mukhopadhyay and Pinder[3] addresses the inherent difficulty of teaching EM, and Crilly[1], Xie, Liang and Wang[4] present laboratory based EM instruction methods. Rao[5], Iskander[6], and Raida[7] address EM instruction using technology; Zhou[8] uses the seminar approach to EM education. With respect to textbooks, Ulaby et al.[9] is a widely used undergraduate EM textbook that includes a good introduction of antenna theory. The classic antennas book by Krauss presents an in depth theory of antennas. Silver[11] covers practical antenna theory and practical projects for the practitioner.

## Portable Analyzer to Enhance the Laboratory Experience

In this section we will describe the various experiments that have been done using the portable analyzer.

### *A. Antenna radiation pattern*

As already stated, the portable analyzer has the capacity to both generate and receive an RF signal. Thus we can measure the radiation pattern of the test or prototype antenna. A test setup for measuring the radiation pattern for test antenna is shown in below Figure 1. As Figure 1 illustrates, the test antenna to be characterized is on the spectrum analyzer (SA) side of the instrument and so we are really measuring its received, not radiated pattern. Because of antenna reciprocity, the radiated and received patterns are identical so it doesn't make any difference which side the test antenna resides. However in the interest of minimizing radio frequency interference, we choose the signal source antenna to be the one with minimal effective radiated power (ERP).

Signal source Test antenna(prototype to be tested)

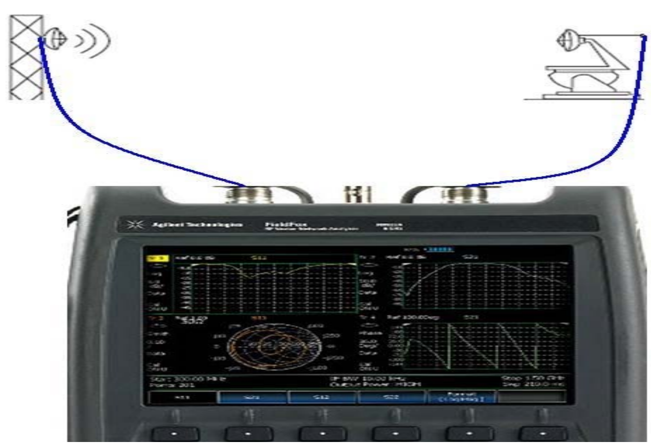

**Figure 1.** Antenna radiation pattern measurement using the Agilent 9912A.

Test antennas we've characterized include (a) the omni-directional vertical, (b) the Yagi, and (c) phased arrays. Figure 1 implies the two antennas are separated by the length of the two transmission lines, and that the test antenna is mounted on a rotor. Given practical coaxial cable length limitations and near/far field considerations, an alternative is to use two separate analyzers, one as a source, and the other operating in SA mode whose input is the test antenna which is mounted on a pole. The student rotates the test antenna and records signal magnitude versus azimuth angle.

In a similar vein, students can observe the effects of different matching systems and how they affect the radiation pattern. For example, with antenna systems that use the Gamma match and coaxial cable – an inherently unbalanced system often results in an asymmetrical pattern. On the other hand, the T-match, and balun, an inherently balanced system, produces a symmetrical pattern.

To make the lab more interesting and engaging to the students, we also use the SA in combination with their designed directional antenna to locate a hidden RF source. We call this "fox hunting." The "fox" is a small low power intermittent 144 MHz beacon that is hidden somewhere outdoors. The students use their directional antenna with the 9912A to find the hidden transmitter. The fox, SA, Yagi and the hunting team are shown in Figure 2

(a) (b)

**Figure 2.** Fox hunting team and their apparatus consisting of (a) the fox, and (b) Yagi, portable SA, and hunting team.

*B. Direction Finding*

Direction finding (DFing) can be done in one of two ways. The first is to use a highly directional antenna such as a Yagi or phased array such that we get the signal source's bearing when the antenna is pointed in the direction that yields the maximum response on the SA. This is the basis for our fox hunting exercise. Because of practical antenna dimensions, this DF method is only feasible at frequencies above 100 MHz. This method works when the directional antenna has a narrow spatial lobe.

The second method of DFing is to use a loop antenna. Note that a loop antenna in the forward and backward direction has a relatively broad spatial lobe and thus would not be suitable for

DFing with respect to maximum intensity. However, in the perpendicular direction, it exhibits an extremely sharp null and thus we locate the source based on the bearing that yields the minimum SA response. Figure 2 shows the setup for a loop antenna to DF on AM broadcast stations. Using triangulation, students have been able to pinpoint a local 980 kHz AM station within less than a km.

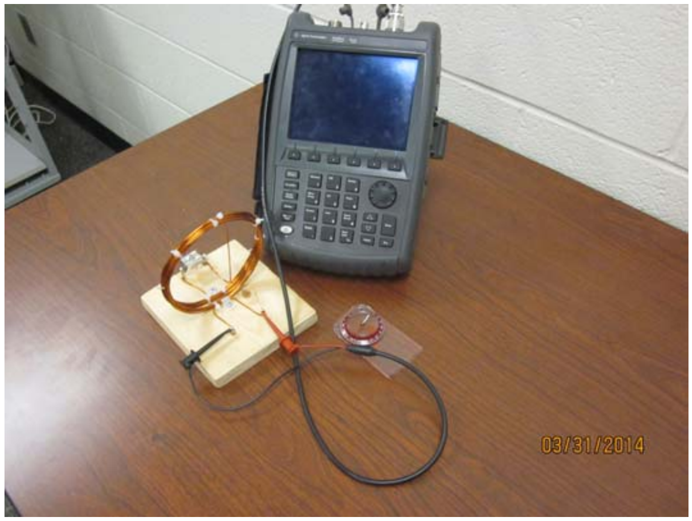


**Figure 3.** Loop antenna to direction find on frequencies below 2 MHz.

*C. Time Domain Reflectometry*

Using the time domain reflectometry capability of the 9912A, we can do the following experiments: (1) given a random length of coaxial cable, accurately determine its length, (2) measure the loss of a given length of coax, and (3) determine the location of a fault (e.g. the fault being a nail inserted at some point in the cable to short the inner and outer conductors). These experiments also force the student to think about how the conductor size and dielectric type affects cable losses and transit times (i.e. velocity factor).

*D. Signal Source and Slotted Line Experiments*

We use a slotted line in conjunction with the signal source to illustrate transmission line behavior in the presence of various loads including opens $(Z_L = \infty)$, shorts $(Z_L = 0)$, perfectly matched $(Z_L = 50\Omega)$, and otherwise $(Z_L = 150\Omega)$. Figure 4 shows the test setup. Because the 9912A's has a maximum output frequency in the GHz range, we have the opportunity to demonstrate that seemingly pure resistive loads whose lead lengths exceed 1 mm will show significant parasitic reactance at frequencies above 200 MHz and thus what we thought was a resistor is really an inductor + resistor.

*E. Antenna Feed Matching*

The 9912A's ability to easily measure SWR provides the student a great deal of flexibility in their antenna designs as well as facilitating the adjustment of the gamma or T match networks.

*F. Dipole types, pattern and SWR*

The antennas course starts out with the development of the basic center fed half-wave dipole antenna. Initially we present its voltage-current profile and show that the feed impedance is 70 ohms. We then we extend the voltage-current profile to illustrate that the feed impedance is still 70 ohms for odd harmonics of the original half wave frequency. To confirm this, we do an experiment using the 9912A in SWR mode to show that for a half-wave dipole at 7 MHz, the SWR is nearly unity at 7, 21, 35...147 MHz. Similarly the student can verify the even harmonics yield an extremely high SWR as predicted by the dipole's voltage-current profile for even wavelengths. Similarly, the analyzer allows us to develop a multiband off center fed dipole with minimal SWR.


**Figure 4.** Test setup for slotted line experiment.

## Conclusions

We have described several ways in which a portable RF analyzer can be used to augment the laboratory experience for a course on antennas and propagation. The source side of the RF analyzer gives us the ability to measure SWR, cable lengths, losses, fault locations and generate antenna test signals. In SA mode, we can characterize patterns of various types of antennas. The portable analyzer can be useful in any capstone courses that require the design of an antenna or other RF component. Presumably, if the student were to try implementing an antenna using any piece of metal, even a bedspring, the analyzer could be used to help design a matching network for minimal SWR and then characterize the radiation pattern.

## References

1 P.B. Crilly, "A novel approach to teaching an undergraduate electromagnetics, antennas and propagation course," presented at the 2013 ASEE NE Section Meeting, Norwich University, March 2013.

2 P.B. Crilly, "An Innovative Approach to Teaching An Undergraduate Electromagnetics Antennas and Propagation Course," presented at the 2014 NE ASEE Section meeting, University of Bridgeport, March 2014.

3 K.T. Selvan, "What is 'student centered' electromagnetic instruction?" [Online]. Available:www.ieeeaps.org/pdfs/Student-centered%20EM%20instruction.pdf.

4 S.C. Mukhopadhyay and D.N. Pinder, "Teaching engineering electromagnetics to information and communication engineering students at Massey University," [Online] Available:http://itee.uq.edu.au/~aupec/aupec03/papers/012%20Mukhopadhyayfull%20paper.pdf.

5 H. Xie, Y. Liang, and Q. Wang, "A laboratory measurement method of radiation pattern," New York:Springer-Verlag, 2012.

6 N.N. Rao, "PC-Assisted Instruction of Introductory Electromagnetics," *IEEE Tran. Educ.*, vol. 33, pp. 51-59, Feb. 1990.

7 M.F. Iskander, "Technology-Based Electromagnetic Education," *IEEE Tran. Microwave Theory and Techniques*, vol. 50, pp. 1020, March 2002.

8 Z. Raida, "Internet Support of Education in Antenna and Microwave Techniques," [Online]. Available:http://ieeexplore.ieee.org/xpl/abstractKeywords.jsp?arnumber=4569883.

9 Z. Zhou, "Seminar-Based Electromagnetics Education," http://www.ieeeaps.org/pdfs/Studentcentered%20EM%20instruction.pdf.

10 Ulaby, F. , Michielssen, E., and Ravaioli, U., "Fundamentals of Applied Electromagnetics ," 6th Ed., Upper Saddle River, NJ: Prentice-Hall, 2010.

11 Silver, H., "The ARRL Antenna Book," Newington, CT: American Radio Relay League, Newington, CT, 2011.


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# Computer Simulation Modeling of a Real System in an Undergraduate Computer Control Systems Laboratory

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## Abstract

This paper presents the procedures for modeling a real time DC motor based on computer simulation in a Computer Control Systems laboratory. The lab is for undergraduate junior level Electrical Engineering students at the United States Coast Guard Academy (USCGA). This laboratory enhances better understanding fundamental engineering concepts via hands on experience. The objectives are to identify a continuous time transfer function of the real time physical system from measurement data and learn the process of computer simulation modeling. The lab provides students a powerful experience to model, analyze, and test the real system with the computer simulation. The computer simulation constantly interfaces in real time with the DC motor.

The processes of computer simulations in this laboratory are summarized in five steps. First, students collect sample data frequency and step responses of the system to realize it. Next, the data acquisition is introduced to students. They look at the collection of data stored in the computer, identify the statistics, and make a proper representation of the system. After modeling the system with the computer simulation, students utilize a verification technique to confirm the model. In the verification students analyze the computer software properly implements the model for the system and it is error free. The final stage of this experimental lab is validation the model. In this step students evaluate the transfer functions via computer simulation properly presents the real system and it is error free. This laboratory requires students to submit formal lab report.

The real time system in this laboratory is a SRV-02 DC motor from Quanser Innovate Educate. The modeling of SRV-02 DC motor is achieved via QUARC software and simulation in MATLAB®. Students in this lab demonstrate achievement of numerous a-k ABET criteria.

## Keywords

Computer simulations, system modeling, verifications, validations.

## Introduction

The United States Coast Guard Academy (USCGA) like many institutions around the world enhances the control systems course with a laboratory for undergraduate Electrical Engineering students. Computer Control Systems is a 3.5 credit hours course in which students meet in the laboratory every other week. Many students have requested to develop additional laboratory for this course based on hands on experience to apply the concepts and theorems from the classroom lectures to applications.

One of the challenges for the students is to create mathematical or computer simulation modeling of a physical system that describes the real system. The main motivation in this paper is to clarify the process between the mathematical modeling, computer simulation, and validation of the modeling for real systems. These procedures allow students to make a bridge between the concept and material they have learned in an undergraduate control system classroom and laboratory with the real world practical applications.

The real time system in this laboratory is a SRV-02 DC motor from Quanser Innovate Educate[1]. The modeling of SRV-02 DC motor is achieved via QUARC software and simulation in MATLAB®[1]. A continuous time transfer function of the system can be obtained from measurement of either the frequency or step response data. This lab allows students to make the connection between the concepts of first order modeling in the control system classroom lectures2 and ultimately, apply them in the laboratory to the real world systems.

Students in this lab demonstrate achievement of numerous a-k ABET criteria. The following ABET outcomes can be assessed in this lab:

**a**. “An ability to apply knowledge of mathematics, science, and engineering.”
**b**. “An ability to design and conduct experiments as well as interpret data.”
**d**. “An ability to function on multidisciplinary teams.”
**e**. “An ability to identify, formulate, and solve engineering problems.”
**g**. “An ability to communicate effectively,” by preparing a formal report.
**k**. “An ability to use techniques, skills, and modern engineering tools necessary for engineering practice.”
**l**. In this laboratory Electrical Engineering students use techniques, skills, and modern engineering tools necessary for engineering practice to apply their basic knowledge of statistics.
**m**. “Possess a basic knowledge of mathematics through differential and integral calculus, basic science, and engineering science necessary to analyze and design complex electrical and electronic devices, software, and systems containing hardware and software components.”

This paper is organized in four sections. The lab experiments are presented first. The lab experiments are included in four main sub-sections to model transfer function for the real system. An informal students’ feedback for this lab is presented next. The last parts of this paper are the conclusion and acknowledgments.

## Lab Experiments

The transfer function of SRV02-DC motor is found from two different experimental methods: measurement of the frequency and step responses[1]. The input to the rotary servo is voltage and the output is angular velocity of the shaft in radian per seconds. The lap period is between 3-4 hours for students working in a group of two. Students are required to submit a formal individual lab report, but they share the measurement data.

The processes of computer simulations in this laboratory are in five processes. First, students collect sample data frequency and step responses of the system to realize it. Next, the data acquisition is introduced to students. They look at the collection of data stored in the computer, identify the statistics, and make a proper representation of the system. After modeling the system with the computer simulation, students utilize a verification technique to confirm the model. In the verification the designer ensure the computer software implements a proper model for the system. The final stage of this experimental lab is validation the model. In this step the students demonstrate the transfer functions via computer simulation properly presents the real system.

### *Part 1) Frequency Response System Identifications*

Frequency response of a linear system can be found by applying a sine wave input signal to a system and recording the output response sine wave. In this lab, the input signal is the motor voltage in volt and the output is the motor speed in radian/seconds. One method to model the system is to keep the amplitude of input voltage constant and vary the frequency. In this method the output amplitude is measured for each frequency setting. The ratio of output and input amplitudes at the same frequency can be used to plot the frequency response of system as Bode magnitude frequency response. One way to define a transfer function for the system is from its Bode magnitude frequency response.

To determine the experimental system transfer function first the steady state gain of the system is found from running the system with a constant input voltage. Then, the gain at different frequencies will be obtained. The frequency response system identification in this lab is in two parts. First students find the steady state gain at frequency of zero. Next they measure the frequency response magnitude by varying the frequency.

### *A. Steady state gain*

Experimentally, the steady state gain is found from running the system with a constant input voltage at zero frequency. In this lab, the steady state gain for the SRV-02 DC motor is obtained by taking the sample data from running the motor. Each group repeats this test for 8 s then calculates the average and standard deviation and record the data. Students measure the maximum speed of the load shaft at zero frequency. In this paper, 5 groups of students' data are reported to show the maximum speed measurement for the motor. Note that each group is working with a different motor, but the input to the motor is 2 volt for each group.

As can be seen from Table 1, there is variation between the different data among the 8 Trials of each group. Infrequently, few groups have the same measurement. The average steady state speed for each group are recorded in Table 1; the variation of average maximum speeds are in the interval of [3.2723, 3.3730] in radian per seconds. The steady state speed standard deviations for each group are recorded in Table 1; the variation of standard deviation speeds between all the groups are in the interval of [0.0057, 0.0089]. The very low standard deviation indicates that the eight tests produce reliable results for the DC motor steady state output response.

Table 1:
Sample Data Measurement for the DC Motor Maximum Speed (radian/seconds) at Zero Frequency (Hz)

| | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 |
|---|---|---|---|---|---|
| Max Speed 1 | 3.3502 | 3.330 | 3.3794 | 3.2504 | 3.351 |
| Max Speed Trial 2 | 3.3648 | 3.335 | 3.3746 | 3.2699 | 3.3721 |
| Max Speed Trial 3 | 3.3599 | 3.328 | 3.3575 | 3.2796 | 3.3697 |
| Max Speed Trial 4 | 3.3624 | 3.333 | 3.3697 | 3.2723 | 3.3794 |
| Max Speed Trial 5 | 3.3599 | 3.333 | 3.3721 | 3.2723 | 3.3721 |
| Max Speed Trial 6 | 3.3721 | 3.328 | 3.3721 | 3.2747 | 3.3648 |
| Max Speed Trial 7 | 3.3648 | 3.335 | 3.3819 | 3.2747 | 3.3746 |
| Max Speed Trial 8 | 3.3746 | 3.318 | 3.3720 | 3.2723 | 3.3770 |
| Max Speed Average | 3.3636 | 3.3308 | 3.3730 | 3.2711 | 3.3701 |
| Speed Standard Deviations | 0.0076 | 0.0057 | 0.0075 | 0.088 | 0.0089 |

The data from one of the groups in Table 1 is used to describe the lab process. The steady-state gain of the DC motor is calculated from the ratio of amplitude of motor maximum speed over the input amplitude constant voltage such as:

$$K_{e,f} = \left|G(j\omega)\right| =: \left|\frac{\Omega_{ave}(j\omega)}{V_m(j\omega)}\right|, \tag{1}$$

where $K_{e,f}$ is the system gain that is a function of motor maximum speed, $\Omega_{ave}(j\omega)$, and the input voltage, $V_m(j\omega)$. Students calculate the steady-state gain in linear and decibel (dB) units. The DC gain from one experience is $K_{e,f} = \left|\frac{4.5398}{2}\right| = 1.6865$, or $K_{e,f} = 4.5398\ dB$.

### *B. System gains at varying frequencies*

To determine the experimental system transfer function the system gains are found from running the system at different frequencies of sine wave input voltage and recording the speed output signal. The procedure is repeated via increment the input frequencies and repeat the measurement and record the amplitude of output maximum speed signal and the gains. The results of this experiment are shown in Table 2.

The plot of frequency magnitude response for decibel gains is shown in Figure 1. The system identification is based on the assumption of first order frequency response. Students use standard Bode magnitude frequency response analysis to identify the system transfer function and the pole location. The pole location guides them to calculate the time constant such as: $\tau_{e,f} = \frac{1}{pole}$ . As can be seen in Figure 1 the time constant, $\tau_{e,f}$ , from this measurement data is estimated at $\tau_{e,f} = \frac{1}{5.79 \times 2\pi} =: 0.0279$ seconds. The overall measurement transfer function for one of the groups is reported as $G_{e,f}(s) = \frac{1.6865}{0.0279s+1}$.

Table 2:
Sample Data Measurement for the DC Motor Maximum Speed (radian/seconds) at Varying Frequencies (Hz)

| F(Hz) | Input Amplitude (volt) | Max Load Speed (radian/seconds) | Gain(linear) | Gain(dB) |
|---|---|---|---|---|
| 0 | 2 | 3.3730 | 1.6865 | 4.5398 |
| .2 | 2 | 3.3137 | 1.6568 | 4.3856 |
| .4 | 2 | 3.3039 | 1.6520 | 4.3600 |
| .6 | 2 | 3.2674 | 1.6337 | 4.2635 |
| .8 | 2 | 3.2820 | 1.6410 | 4.3022 |
| 1 | 2 | 3.3112 | 1.6556 | 4.3792 |
| 1.2 | 2 | 3.2869 | 1.6434 | 4.3151 |
| 1.4 | 2 | 3.2114 | 1.6057 | 4.1133 |
| 1.6 | 2 | 3.2382 | 1.6191 | 4.1855 |
| 1.8 | 2 | 3.1700 | 1.5850 | 4.0006 |
| 2 | 2 | 3.1262 | 1.5631 | 3.8797 |
| 3 | 2 | 2.9046 | 1.4523 | 3.2412 |
| 4 | 2 | 2.7585 | 1.3793 | 2.7929 |
| 5 | 2 | 2.5150 | 1.2575 | 1.9902 |
| 6 | 2 | 2.3348 | 1.1674 | 1.3445 |
| 7 | 2 | 2.1546 | 1.0773 | 0.6469 |
| 8 | 2 | 2.0280 | 1.0140 | 0.1208 |
| 9 | 2 | 1.8796 | 0.9397 | -0.5398 |

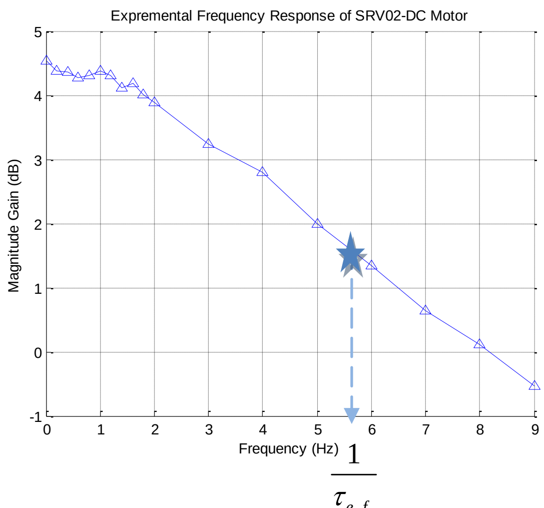


Figure 1. Experimental frequency response of SRV02-DC motor

### *Part 2) Step Response System Identifications*

In the step response experiment students configure the signal generator input with a square wave. Students measure the corresponding load shaft speed as the output of system. The system gain $K_{e,s}$, can be determined from the measurement data in Figure 2, and by the following equation:

$$K_{e,s} = \frac{\Delta y}{\Delta v} =: \frac{y_{ss} - y_0}{v_{\max} - v_{\min}}, \tag{2}$$

where, $y_{ss}$ is the steady state output value, $y_0$ is the initial output value, $v_{\max}$ is the maximum input value, and $v_{\min}$ is the initial minimum input value.

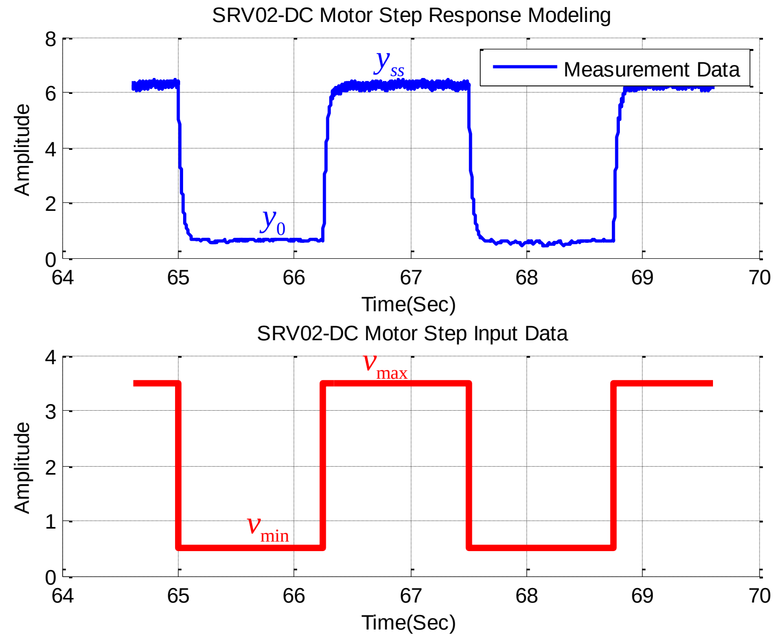


Figure 2. Experimental step response of SRV02-DC motor

The time constant with the assumption of first order system identification can be determined graphically such as:

$$\begin{aligned} y(t_1) &= 0.63 y_{ss} + y_0 \\ \tau_{e,s} &= t_1 - t_0 \end{aligned}, \tag{3}$$

where , $y(t_1)$ is 63% of the maximum measurement output amplitude that is happening at time $t_1$. The time constant is, $\tau_{e,s}$, and output starting time measurement is $t_0$.

Students repeat the measurement of $K_{e,s}$ from equation (2) and $\tau_{e,s}$ from equation (3) for at least 8 trials as can be seen in Table 3. Then the average and standard deviation of gains $K_{e,s}$, and time constants $\tau_{e,s}$ , are calculated and reported in Table 3. The very low standard deviations for both gains and time constants Trials indicate that the eight tests produce reliable results for the DC motor measurement output step response modeling. The modeling transfer function of the step response for one of the groups is reported as: $G_{e,s}(s) = \dfrac{1.7856}{0.0378s + 1}$.

Table 3:
Sample Data Measurement for the DC Motor for Step Input Response

| | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 | Trial 7 | Trial 8 |
|---|---|---|---|---|---|---|---|---|
| Gain Measurement | 1.747 | 1.773 | 1.794 | 1.833 | 1.806 | 1.768 | 1.778 | 1.781 |
| Time Constant Measurement (seconds) | 0.035 | 0.036 | 0.034 | 0.034 | 0.050 | 0.042 | 0.036 | 0.035 |
| Average Gain: $K_{e,s}$ Standard Deviation | | | | | 1.7856 0.0261 | | | |
| Average Time Constant: $\tau_{e,s}$ (seconds) Standard Deviation | | | | | 0.0378 0.056 | | | |

### *Part 3) Model Verification*

Verification is a process of finding that the computer implementation of a model is error free. One way of verification is to compare the computer calculation with the mathematical model that is defined by the analyst. In this class students have already learned the mathematical modeling of a DC motor in general[2]. They have a good understanding of electromechanical system modeling. Verification technique is used to analyze the computer simulation presents a proper modeling for the SRV-02 DC motor and it is error free.

A mathematical derivation of dynamic behavior of the load shaft speed, $\omega_l(t)$, as a function of motor input voltage, $V_m(t)$, for SRV02 DC from Quanser Innovate Educate1 lab handout is given as:

$$\dot{\omega}_l(t)J_{eq} + \beta_{eq,v}\omega_l(t) = A_m V_m(t)\,, \tag{4}$$

where, $J_{eq}$, $\beta_{eq,v}$, and $A_m$ are the equivalent moment of inertia, equivalent damping terms and the actuator gain, respectively. This model is well-known to the students. Students are asked to determine the transfer function of SRV02 DC motor as $\frac{\Omega(s)}{V_m(s)} =: \frac{motor\ speed}{voltage}$, for the given value of $Jeq = 0.00213\,\text{Kgm}^2$, $\beta_{eq,v} = 0.0844\,\text{Nms/rad}$, and $A_m = 0.129\,\text{Nm/V}$1. Taking the Laplace transform of the modeling equation and simplifying the equation gives the following general first order transfer function:

$$\frac{\Omega(s)}{V_m(s)} = \frac{K}{\tau s + 1}\,. \tag{5}$$

Students calculate the steady state gain, $K$, and time constant, $\tau$, values, and then verify them with the experimental results in Part 1 and Part 2 of this lab and report the data in Table 4. The mathematical modeling of the system is a function of gain, $K$, and time constant, $\tau$ such as:
$$G(s) = \frac{1.528}{0.0252s + 1}\,.$$

### *Part 4) Validation*

Validation is a process of finding that the computer simulation modeling properly represents the real system. The goal is to clarify, how closely different modeling presents the actual real system transfer function. In this part of lab, students compare the model parameters they have found in the previous (frequency and step) experiments. In the validation process students evaluate how the computer software implements a proper model for the system and it is error free.

In validation process, students test the two different transfer functions experimentally and validate each one of the model parameters. Table 4 presents the summary of all the designs from one of the groups. As can be seen in Table 4 the validation coefficients are fairly close to most of the response experiences. The real system transfer function can be achieved over the validation process by tuning the gain and time constant as the hardware interfacing in real time with the computer software. The result of modeling coefficients for the validation parameters ($K_{e,v} = 1.675$, $\tau_{e,v} = 0.026$ seconds) step response and the real experimental data of DC motor are shown in Figure 3. This Figure shows the computer simulation modeling reasonably presents a proper model for the system and it is error free.

Table 4:
Sample Data Measurement of Steady State Gains and Time Constants

| Section | Description | Symbol | Value | Unit |
|---|---|---|---|---|
| Frequency Response: Part 1 | Steady state gain:<br>Time constant: | $K_{e,f}$<br>$\tau_{e,f}$ | 1.6865<br>0.0279 | <br>seconds |
| Step Response: Part 2 | Steady state gain:<br>Time constant: | $K_{e,s}$<br>$\tau_{e,s}$ | 1.7856<br>0.0378 | <br>seconds |
| Verification Response: Part 3 | Steady state gain:<br>Time constant:: | $K$<br>$\tau$ | 1.528<br>0.0252 | <br>seconds |
| Validation Response: Part 4 | Steady state gain:<br>Time constant: | $K_{e,v}$<br>$\tau_{e,v}$ | 1.675<br>0.026 | <br>seconds |

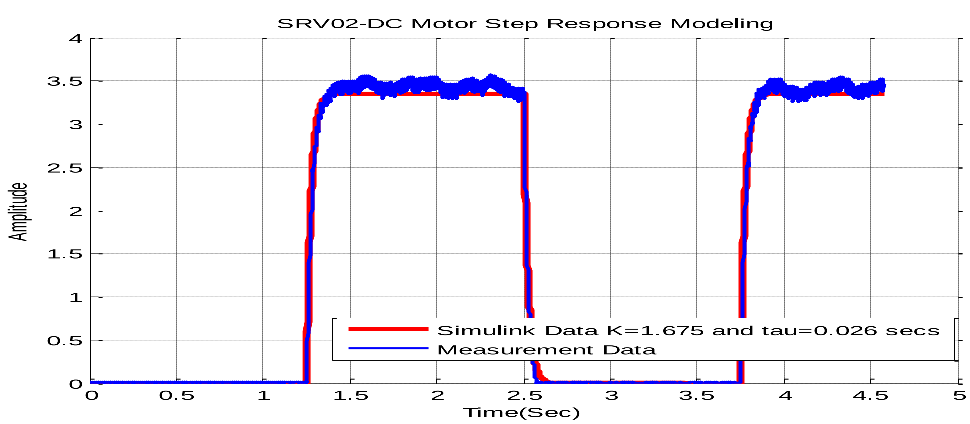


Figure 3. Experimental step response of SRV02-DC motor for the validation process

## Students' Feedback

*"The most beneficial lesson I learned in this lab is how to use a motor system and Matlab together to find the transfer function of the motor. I learned the most in how to configure the settings in QUARC, and I learned the least in the theoretical section of the lab because I had prior knowledge in that section from class; however, it was still beneficial to review."*

*"From this lab, I learned how to use Simulink and how to verify simulation results. The part of the lab I learned the most from was Part 3B, because everything we learned from the lab was tied together. I learned the least in Part 1."*

*"The key thing I learned was how accurately you could model a real world system using a simulation without having to worry about nonlinearity in the simulation. In this lab I learned the most from Part 3 where we compared the different models found using the three methods. I learned the least from Part 1 because it was easy to follow the instructions and understand what to find."*

*"Carrying out lab 2 helped students to become more familiar with the Quarc interface in MATLAB®. The verification and validation sections were very informative and gave students an idea of how computer modelling was fine tuned to give the best results. The frequency response measurements were very time consuming, but important for getting quality data. Overall, lab 2 was very insightful and helped reinforce concepts learned in class."*

*"This lab was very instructional and through it a learned several things. One of the main areas of learning was in using the QUARC software. It was the first time I had encountered this software and it required a steep learning curve. Overall this lab served to increase my understanding of systems and different ways that they can be modelled."*

*"I learned a myriad of things about the different types of responses used to realize a system along with ways to use MATLAB® to obtain the gain and time constant of a response. The section that I learned the most from was definitely Part 3 where it brought the whole lab together. The part where I learned the least was Part 3A."*

*"From this lab, I gained a new understanding for how products are tested in various electronic industries. The part of the lab that I learned the most from was the frequency response experiment. I learned from it that the gain of the system is actually calculated at its steady state. I was taught that previously, but it did not click into my mind until I actually had hands-on experience with it. The section that I learned least was the last part of the lab where I adjusted the K and τ parameters because it did not require a lot of intuitive thinking. In summary, I would like to state that this lab was really useful in helping me comprehend the procedure and necessity of testing products in the industries."*

*"A new lesson I learned from this lab is that the combination of electrical and mechanical equations produces accurate results. Before taking this class, I had no idea that it was possible to model a system mechanically and analyse it in electrical parameters. The part of the lab I learned the most was the verification process at the end of the lab. From calculating nominal*

*values to hand tuning gain and tau, I truly gained an understanding and appreciation for the actual system response of the SRV02. The part of the lab where I learned the least was the bump test experiment. I thought using ginput to measure points off the measured step response and calculating gain and time constant was a little bit confusing initially."*

*"From this lab I learned the critical importance of being able to model a system using frequency response and step response. I learned the most from applying sinusoids of varying frequencies to the system to find its frequency response. I learned the least from the validation part of the lab because I felt like I had less time to complete it and was only trying to produce graphs."*

*"In this lab, we learned that Matlab control tool box is very useful for modeling a mathematical system and analyse it. Also, Matlab can help to verify and validate the system."*

*"I learned the most in part three of the lab as it brought all elements of the lab together. This lab has taught me how a system can be realized through software."*

## Conclusions

This paper presented the procedures for modeling a real time DC motor based on computer simulation in a Computer Control Systems laboratory. This laboratory improved better understanding of the fundamental of computer modeling concepts via hands on experience for undergraduate students. The first order continuous time transfer function of the real time physical systems was identified from the measurement frequency and step responses. The lab provided students a powerful experience to model, verify, and validate the real system transfer function with the computer simulation.

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## References

1 J. Apkarian, M. Lévis, and H. Gurocak, "SRV02 Rotary Servo Base Unit Lab Experiments," Quanser Inc., 2011.

2 Norman S. Nise, Control Systems Engineering, John Willy and Sons. Inc., River St. Hoboken, NJ, 2015.

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# Audio and Vision Projects Augmenting a Studio Style Lab Experience in a Signal Processing Course

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## Abstract

Engineering students greatly benefit from laboratory education and team projects, as these types of experiences prepare students for internships, research projects, and entry into the engineering profession. Unfortunately, laboratory classes can be difficult to fit into the course load of an engineering program at a liberal arts-focused university, where students are exposed to significant breadth, as well as sufficient depth in their engineering education. One solution to this challenge is to incorporate laboratory experiences in a mixed learning approach, which includes laboratory experiences provided by both in-class studio labs and larger take-home projects. This work briefly describes the mixed-learning method and provides further details on the projects employed in a multidisciplinary digital signal processing course. This work also describes the blind review method that is used to assess student learning to judge the success of this method.

## Keywords

Blind review; Mixed Learning; Take-home projects; Reverberation; Computer Vision

## Introduction

It is commonly held knowledge that laboratory experiences are an essential component of engineering education. Engineering students associate lecture with an environment of testing and calculation, while they identify laboratory experiences as a place of applying and understanding[1]. The chief principle of engineering is the manipulation of the physical world for the betterment of humankind, and thus most engineering students require the knowledge that results from hands-on experience[2,3]. As a result, it is important to incorporate a variety of laboratory experiences into engineering courses, as these experiences prepare students for entry into the profession of engineering.

Engineering programs at liberal arts-focused universities face the challenge of fitting laboratory specific courses into their curriculum, as students are expected to become well-rounded individuals while also pursuing deep technical knowledge in their engineering education. In addition to this challenge, undergraduate-focused schools require faculty members or adjunct instructors to teach laboratory courses, due to a lack of graduate students, which limits the availability of such courses. One possible solution to this issue is to institute a mixed learning laboratory approach, in which eight lecture periods throughout the semester are replaced with in-class studio laboratory exercises and larger take-home lab projects are assigned to encourage students to refine skills by applying skills learned through in class lab assignments[4].

This method is currently being implemented in an introductory digital signal processing (DSP) course. This course was chosen because previous work has demonstrated that hands-on experiences in DSP courses can increase student's desire to learn[5]. Additionally, DSP laboratory exercises are typically software based, not requiring any further hardware than student's personal laptops, which makes the mixed learning approach feasible[6]. Finally, the course possesses a relatively small student population from a variety of disciplines, making it a good choice for applying this method.

The studio laboratory exercises are designed to be typical of a laboratory style DSP course, but one key to this method is to design take-home projects that provide students with exposure to research methodologies, allow them to refine skills learned from in-class laboratories, and also provide a method for assessing student learning. This work presents several projects that have been developed for this course, as well as a blind-review assessment method for these take-home projects.

## Mixed Learning Approach

The mixed learning approach is split into two distinct parts that yield a cycle of experiential learning. The initial component is independent student work during in-class studio laboratory exercises. These exercises are implemented in place of eight lectures over the course of the semester, and require students to use their laptops to implement software-based exercises. The skills developed through these exercises are then applied to challenging take-home laboratory projects completed in small groups. These projects require students to research topics and identify novel applications or methods based on skills that they have developed through the studio lab exercises. These projects lead to a refinement of student skills, which serves to inform future studio lab exercises. The process of learning, applying, and refining skills can be visualized by the flow chart shown in Figure 1, which shows the mixed learning laboratory approach[4].

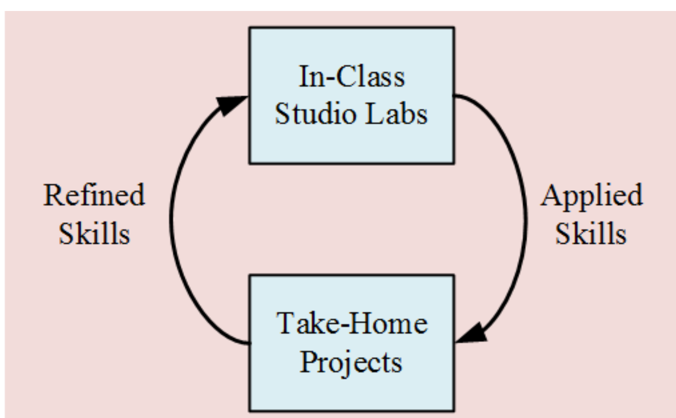


**Figure 1: Mixed learning laboratory approach**

## Studio Laboratory Exercises

The studio laboratory format requires students to apply lecture concepts directly to in-class programming assignments on their personal computers[7]. This is facilitated by student access to a university supported cloud based virtual desktop service that provides necessary simulation software anywhere with high-speed Internet access. The software packages used in this course are MATLAB and SIMULINK. Labs are implemented in place of eight lectures spread throughout the course. It is notable that these labs could also be delivered remotely, thanks to the ready access to simulation software.

Studio laboratory exercises are designed to cover skills related to key topics in DSP and to develop proficiency in these skills. The number of labs is constrained to eight to provide sufficient coverage between lecture and laboratory exercises. A detailed listing of the lab material is shown in Table 1, and is based on previous work that has identified essential DSP topics[5,6].

**Table 1: Studio Lab Experiments**

| **Studio Lab** | **Description** |
|---|---|
| Lab 1 | Discrete Signals and Systems |
| Lab 2 | Audio Processing |
| Lab 3 | Fast Fourier Transform |
| Lab 4 | Filter Design |
| Lab 5 | Point/Area Image Processing |
| Lab 6 | Blob Detection |
| Lab 7 | Edge Detection |
| Lab 8 | Equalization & Watermarking |

Although these labs provide a broad exposure to essential DSP topics, they do not give students a chance to refine their skills. In order to provide this opportunity, several take-home lab projects were developed. These projects are detailed in the next section.

## Audio and Vision Projects

Designing projects can present a distinct challenge to this method. It is important to find applications that are interesting, easy enough to understand, and allow students to refine skills learned in studio labs. Students are required to work in groups to complete laboratory projects outside of class[8]. The projects chosen for this course are applications of signal processing concepts to audio processing and computer vision. These applications were chosen because students are able to hear, in the case of audio processing, or see, in the case of computer vision, the direct results of their efforts.

Student groups are required to research topics related to each project and propose a topic for further study by submitting an abstract that explains the proposed work. The student groups then are required to attempt to develop a novel advancement in the field of audio processing or computer vision. The resulting work must then be collected into a short (4 page) research paper in the IEEE format. The research paper is submitted to a blind review process to assess student learning that is detailed in a later section.

The first project provided to students is an application of signal processing to reverberation. Reverberation is the collection of reflected sounds from the surface of an enclosed space. This results in a muddy or darkened sound that differs from the direct sound. This acoustic phenomenon is common in real-life, and presents an interesting topic for exploration. The reverberation phenomena can be modeled using a set of delays and all-pass filters, which are DSP topics covered in the studio labs of this course. Figure 2 displays a block diagram representation of a simple reverberator[9]. Students were able to build block diagram models of reverberation algorithms similar to that shown by using MATLAB and SIMULINK.

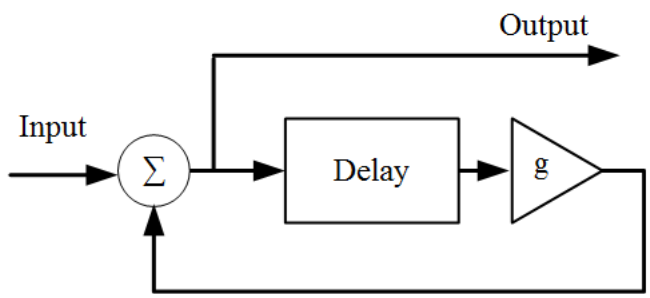


**Figure 2: Simple Reverberation**

Student groups were tasked with exploring topics related to reverberation, and developing a novel advancement in this area. These groups were given the chance to choose topics for their projects based on the principles of reverberation. The topics chosen for further exploration included:

- Dereverberation
- Modulation
- Wavelet domain reverberation
- Development of new reverberation algorithms

The second project requires students to apply DSP techniques to applications in computer vision. Students are given the choice of two topics for exploration: image classification and object tracking in video. Each of these possible projects is detailed below, along with areas of exploration for student groups.

The first option is to explore image classification using the bag of words technique, most prolifically demonstrated by Csurka, et al. in 2004, which can be applied to a variety of date sets[10]. Students may use the Caltech computational archive as an image set, which can be found online at http://www.vision.caltech.edu/html-files/archive.html. The bag of words algorithm consists of four main processes:

1. Feature extraction

2. Clustering/quantizing
3. Learning class conditional models (a visual dictionary so to speak)
4. Classification of new data

Student groups were able to choose from a number of topics to provide refinements to this method. Students could explore variations in feature extractors, a variety of clustering methods, and different classifiers to see how these parameters affect algorithm performance. Figure 3 shows an example of an image from the Caltech archive after feature extraction and clustering was performed.

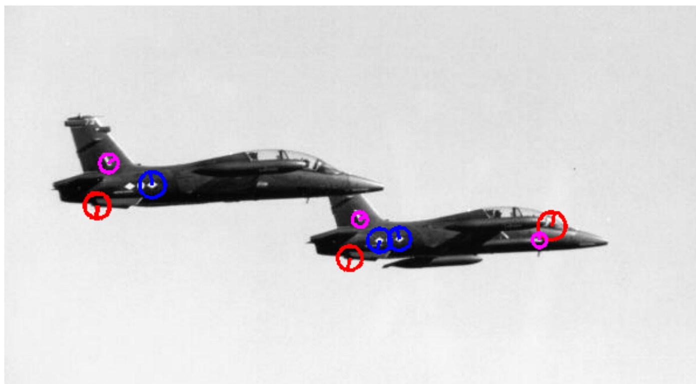

**Figure 3: Bag of words image classification example**

The second option available to students for this project is for students to investigate methods for tracking objects in video. Although tracking of single objects through video is a largely explored and well documented, the ability to track multiple objects through video is still problematic[11]. This problem is made more challenging if the objects are largely identical. This motivates exploration of methods to match objects between frames for efficient tracking. As such, a video data set was created of white Ping-Pong balls in a box lid with a dark background that is agitated so the balls are moving. Figure 4 shows an example frame from this video.

**Figure 4: Still frame for multiple-identical blob tracking**

The algorithm for tracking is broken down into three phases:

1. Blob detection with non-maximum supression[12]
2. Scoring for blobs in consecutive frames
3. Matching blobs in consecutive frames[13]

Under this understanding, student groups were able to choose from among several topics, including further development of the non-maximum suppression algorithm, exploration of a variety of scoring functions, and the analysis of different matching algorithms. Students were then asked to apply their methods to several new data sets to test the efficacy of the algorithms.

## Multidisciplinary Teams

The student population is broken down into small multidisciplinary teams of 2 or 3 students for work on the projects presented in this paper. The overall student population is composed of 11 students from a variety of disciplines. The student distribution among disciplines is displayed in the pie chart in Figure 5. From this, it is possible to see that Computer Science majors make up the largest component of the population, with 46% of the students having the CS discipline. The remaining population is composed of engineers, with the Electrical Engineering discipline having the largest contingent, with smaller contingents of Computer and Mechanical Engineering providing smaller portions. This population leads to a necessary interdisciplinary dynamic in project groups.

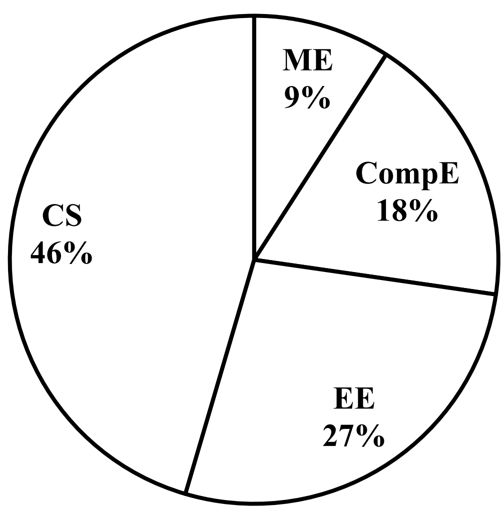


**Figure 5: Student distribution by discipline**

## Assessment

In order to directly assess student skills, work from the take-home projects must be submitted as short (4 page) technical research papers in IEEE format. This allows for a direct mapping of skills to results that can be easily assessed. Although surveys can be used as an indirect measure of student learning, the student's perceived knowledge is often much different than actual student performance[14].

The technical papers are submitted to several faculty members with familiarity in the subject area for blind review. These faculty members are then asked to rate the student papers as a measure of student ability using a prescriptive rubric, which is shown in Table 2. This rubric breaks the paper down into smaller parts, which includes demonstrated student knowledge, application, justification, and originality. The reviewers are then required to assign a decision of accept, revise, or reject to each paper based on the prescriptive rubric. A total overall score between 9 and 12 requires a decision of accept, while scores between 6 and 9 yield a decision of revise, and scores less than 6 are an automatic rejection. In addition to the overall score, reviewers will be asked to provide comments to each student group that serve to inform revisions and improve future work. These comments provide students with feedback regarding their skills, and allow for appropriate adjustments to be made.

**Table 2: Prescriptive rubric**

| | **Excellent (2)** | **Adequate (1)** | **Weak (0)** |
|---|---|---|---|
| **Format** | Paper follows the IEEE format and is easy to read | Minor formatting or structure issues | Major formatting or structure issues |
| **Writing** | The writing is clear and mostly free from grammatical mistakes | Minor grammar mistakes, unclear presentation | Major grammar mistakes, unclear presentation |
| **Knowledge** | Clear knowledge of theory | Some knowledge of theory | Poor knowledge of theory |
| **Application** | Results displaying high proficiency in applied skills | Results displaying some proficiency in applied skills | Results displaying poor proficiency in applied skills |
| **Justification** | Clear justification of methods used | Some justification of methods used | Poor justification of methods used |
| **Originality** | Novel concept or application | Somewhat novel concept or application | Unoriginal concept or application |

To assess the success of this method, rubric scores from the first project set may be compared against scores from the second project. It is expected that student groups will use feedback from the first set of projects to improve performance in the second project. It is also expected that student skills will be further refined through the iterative mixed learning process.

Another tool that can be used to assess the success of the mixed learning method is the submission of student work to conferences. Students are encourages to submit their papers to the IEEE Region 1 Student Conference Paper Competition and as poster abstracts to an ASEE Section Conference. The judging and acceptance for these opportunities will provide useful information on the successful implementation of the mixed learning method.

## Conclusions

This work provides a brief description of a mixed learning method that allows for the incorporation of laboratory experiences in a non-laboratory specific course. This work lists the laboratory exercises used for in class studio style labs and also provides explanations of several audio and vision take-home projects used to augment the in class labs. Finally, this work delivers a blind review assessment framework to test the success of the mixed learning method.

Students are currently undertaking the projects explained in this work. While the results of these projects are yet to come, informal student response has been generally positive. These projects provide students with a taste of productive work in multidisciplinary groups, and require students to use written communication to describe their work. These skills alone are enough justification for the method, as they are necessary of participants in the engineering profession. In addition to this, these projects also provide students with invaluable research experience that is an important component of undergraduate engineering education[15].

Upon the completion of this course, results will be evaluated, and a follow up paper will report the results of this approach. Topics for future work include the application of this method to other courses, including Dynamic Modeling and Control and Electromagnetic Theory. In addition, further refinements will be made to both the laboratory design and the assessment strategy.

## References

1 Lin, Chia-Ching and Chin-Chung Tsai. “The relationships between students’ conceptions of learning engineering and their preferences for classroom and laboratory learning environments,” Journal of Engineering Education, Vol. 98, No. 2, 2005, 193-204.

2 Feisel, Lyle D. and Albert J. Rosa. “The role of the laboratory in undergraduate engineering education,” Journal of Engineering Education, Vol. 94, No. 1, 2005, 121-130.

3 Abdulwahed, Mahmoud and Zoltan K. Nagy. “Applying Kolb’s experiential learning cycle for laboratory education,” Journal of Engineering Education, Vol. 98, No. 3 July 2009, 283-294.

4 McPheron, Benjamin D. “A Mixed Learning Approach to Integrating Digital Signal Processing Laboratory Exercises Into a Non-Lab Junior Year DSP Course,” 2015 Mid Years Engineering Experience Conference, March 22-24, 2015.

5 Adams, J. and F. Mossayebi. “Hands on experiments to instill a desire to learn and appreciate digital signal processing,” Proceedings of the 2004 American Society for Engineering Education Conference & Exposition, 2004.

6 Ossman, Kathleen. "MATLAB/SIMULINK lab exercises designed for teaching digital signal processing applications," Proceedings of the 2008 American Society for Engineering Education Conference & Exposition, 2008.

7 Whitmal III, Nathaniel A. "Implementation and assessment of a studio-style laboratory in real-time digital signal processing," Proceedings of the 2002 American Society for Engineering Education Conference & Exposition, 2002.

8 Jouaneh, Musa K. and William J. Palm, III. "System dynamics experiments at home," Proceedings of the ASME 2009 International Mechanical Engineering Congress & Exposition (IMECE2009), November 13-19, 2009.

9 Browning, Paul L. "Audio digital signal processing in real time," A problem report submitted in partial fulfillment of the requirements for the degree of Master of Computer Science, West Virginia University, 1997.

10 Csurka, Gabriella, Christopher R. Dance, Lixin Fan, Jutta Willamowski, and Cedric Bray. "Visual categorization with bags of keypoints," Workshop on statistical learning in computer vision, ECCV 1 (1-22), 2004.

11 Williams, Oliver, Andrew Black, and Robert Cipolla. "Sparse Bayesian learning for efficient visual tracking," IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 27, No 8, August 2005, 1-13.

12 McPheron, Benjamin D., Vincent H. Crespi, Robert Collins and Yanxi Liu. "Automatic detection of exploding aggregates in a colloidal suspension," CSE Technical Report No. 14-002, January 29, 2014 Pages 1-7.

13 Kuhn, Harold W. "The Hungarian method for the assignment problem," Naval research Logistics Quarterly, 2 (1955) 83-97.

14 Bernadin, Shonda. "A paradigm for assessing student learning in an introductory digital signal processing course", Proceedings of the 2007 American Society for Engineering Education Conference & Exposition, 2007.

15 Zydney, Andrew L., Joan S. Bennett, Abdus Shahid, and Karen W. Bauer. "Impact of undergraduate research experience in engineering," Journal of Engineering Education, Vol. 91, No. 2, 2002, 151-157.


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# Impact of hands-on first year course on student knowledge of and interest in engineering disciplines

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*Quinnipiac University*

## Abstract

This paper is the second in a longitudinal study that will correlate student success with the student's initial knowledge and interest in his/her chosen engineering major. Success has two facets. For the students, success can be determined by their satisfaction with their choice of major and timely graduation. For the university, success is determined by retention of the students for the program duration. This particular paper focuses on a hands-on, introductory engineering course mandatory for all incoming engineering students. The course provides career and technical information on the four engineering disciplines offered at Quinnipiac University. The following four questions are investigated: Is there a correlation between a student's initial desire to pursue a specific engineering major and their actual and perceived knowledge of that engineering discipline? For those students who are interested in and knowledgeable about a specific engineering discipline, does the introductory course strengthen that interest? For those students who are unsure about what specific engineering discipline to choose, are the students more likely to be interested in a specific engineering discipline at the end of the course? Does the introductory course increase students' knowledge, actual and perceived, about the specific engineering disciplines? A pre- and post-course survey evaluates student interests and knowledge in each of the four disciplines. The analysis of survey results is the first step of the longitudinal study. Few statistically significant conclusions can be drawn at this point due to the relatively small sample size in each of the four disciplines. However, the work presented in this paper is valuable as a result of the framework presented and the preliminary analysis.

## Key Words

Freshman engineering, first-year engineering course

## Introduction

Student retention in engineering programs has been studied for many years. The focus of such studies has varied from the personal characteristics the students bring with them to college to the impact of their experience in college. Early research revealed that the personal characteristics of students entering college, such as high school GPA, SAT scores, demographics, as well as attitudes and personalities, play a factor in student retention in college in general.[1,2,3] Later research focused on these characteristics specifically related to engineering retention.[4] Other studies have investigated the role that the students' college experiences have on their retention. These studies found that there were two factors at play in retention. The first was academic, which included poor teaching and advising and curriculum difficulty. The second was a feeling of lack of belonging in engineering.[5,6]

In part to facilitate retention, many colleges offer a first year engineering course.[7] Most are designed to be an active, hands-on learning environment that develop a sense of community and peer support network, which can overcome that feeling of a lack of belonging. With quality instruction, faculty mentoring, and instructor accessibility, the issues of poor teaching and advising can be overcome as well.

Quinnipiac University offers majors in four engineering disciplines: civil, industrial, mechanical and software. A course common to all engineering majors is a 3 credit hour introductory engineering course that is required for all first semester engineering students and open to all students at the university. Half of the student outcomes in the course are focused on the engineering profession: explain the basic practice of engineering, describe background histories, impact on society, skills employed, and professional/ethical responsibilities; summarize the knowledge bases, skills, problem types, and analysis techniques of the four engineering disciplines offered at Quinnipiac University; and analyze information provided and learned to make an informed decision about choice of an engineering major. These outcomes are focused on raising student knowledge of engineering disciplines in order to enhance their ability to make an informed decision about choice of an engineering major.

An important part of the course designed to solidify the class discussions is the hands-on activity that follows each of the modules associated with the four majors. This has been proven to be an effective technique in improving student learning.[8] Research has also shown that discipline-specific activities are more effective in motivating students to develop their own understanding[9]; as a result, the introductory course was designed with hands-on activities related to the particular engineering major, rather than engineering in general. The civil engineering module requires student teams to build a pasta tower to a specific height, using a specified bill of materials, to hold various volumes of water. The tower then has to withstand vibrations on an earthquake table. The industrial engineering activity involves the seat design of a commercial airline, as well as optimizing the routing of the airplane to maximize revenue generation. For the Mechanical Engineering module, student teams design and build a water-powered rocket, using a 2L soda bottle. Lastly, for the software engineering module, student teams designed, developed, documented and presented an Android app, using MIT App Inventor.

At the start of the course students are surveyed to collect data on the major in which they are currently registered, initial actual knowledge of engineering disciplines, initial perceived knowledge of engineering disciplines, initial interest in a specific engineering major, and reasons for selecting engineering (or taking course for non-engineering majors.) The same survey was distributed to the students at the end of the course. The results of surveys are used to analyze the following four questions. We recognize that students' knowledge and interest are affected by their greater environment, most notably interaction with other students. However, we assume the knowledge gained through the course to have a greater effect on the students' evolution of knowledge and interest, evaluated through the pre- and post-course surveys.

This paper investigates four topics:

1. Is there a correlation between a student's initial desire to pursue a specific engineering major and their actual and perceived knowledge of that engineering discipline?

2. For those students who are interested in and knowledgeable about a specific engineering discipline, does the introductory course strengthen that interest?
3. For those students who are unsure about what specific engineering discipline to choose, are the students more likely to be interested in a specific engineering discipline at the end of the course?
4. Does the introductory course increase students' knowledge, actual and perceived, about the specific engineering disciplines?

In the fall 2013 and 2014 semesters, 155 students completed the initial knowledge survey in the course. At the beginning of the semester, 17 of these students had declared a major other than engineering (not engineering), and 32 were undeclared engineering majors. The remainder had declared one of the four engineering majors offered at Quinnipiac University: 26 Civil Engineering (CE) majors, 7 Industrial Engineering (IE) major, 48 Mechanical Engineering (ME) majors, and 25 Software Engineering (SE) majors. As will be discussed later in the paper, it is difficult to make quantitative judgments about all four of the above topics due to the small sample size for most of the majors. However, some qualitative observations can be made about the data.

**Question 1: Is there a correlation between a student's initial desire to pursue a specific engineering major and their actual and perceived knowledge of that engineering discipline?**

The information to answer this question was taken from the initial survey. The students were asked to define each of the disciplines and then indicate how confident they were in their definitions on a Likert scale where 1 was very unsure and 5 was very confident. Discipline-specific faculty members then rated the students' definitions, also on a Likert scale. The students were also asked their level of interest in each of the four disciplines offered by the university:

I am considering pursuing the following disciplines: (Circle the appropriate number):
1- Strongly disagree 2- Disagree 3- Neutral 4- Agree 5- Strongly Agree

| | | | | | |
|---|---|---|---|---|---|
| a) Civil Engineering | 1 | 2 | 3 | 4 | 5 |
| b) Industrial Engineering | 1 | 2 | 3 | 4 | 5 |
| c) Mechanical Engineering | 1 | 2 | 3 | 4 | 5 |
| d) Software Engineering | 1 | 2 | 3 | 4 | 5 |

**Figure 1 – Survey question to determine level of interest**

The students' interest and their perceived knowledge (how confident they were in their definition) in each discipline were plotted and compared with a plot of the students' interest and actual knowledge (the rating of the students discipline definition by the faculty). As shown in Figures 2-5, there appears to be no correlation between the students' interest in a particular discipline, and their knowledge of that discipline. In the figures, each dot represents a single student's response. It is important to track the number of responses; therefore, points that would otherwise be overlaid are displayed closely alongside each other.

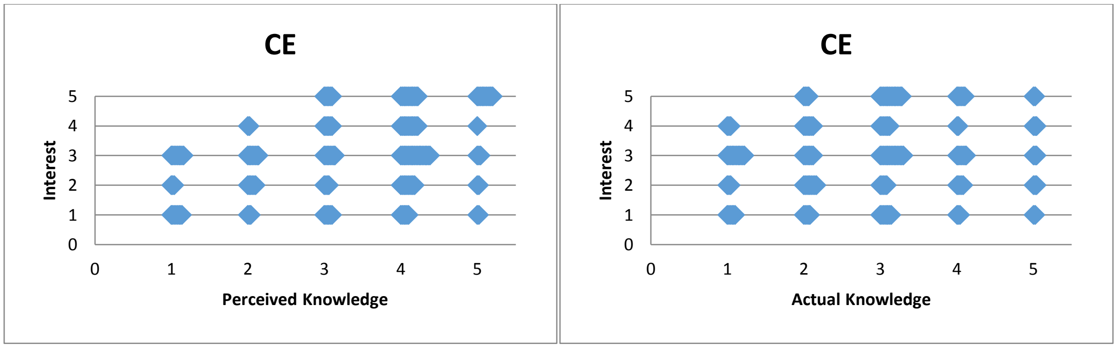


**Figure 2. CE Interest vs Actual and Perceived Knowledge**

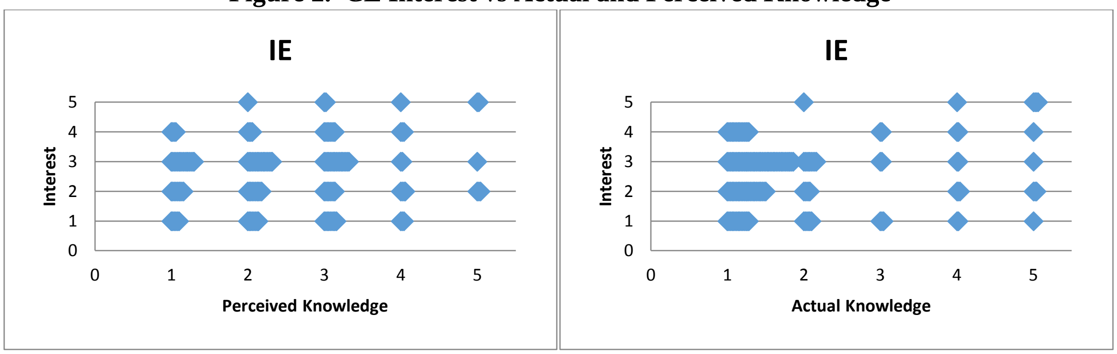


**Figure 3. IE Interest vs Actual and Perceived Knowledge**

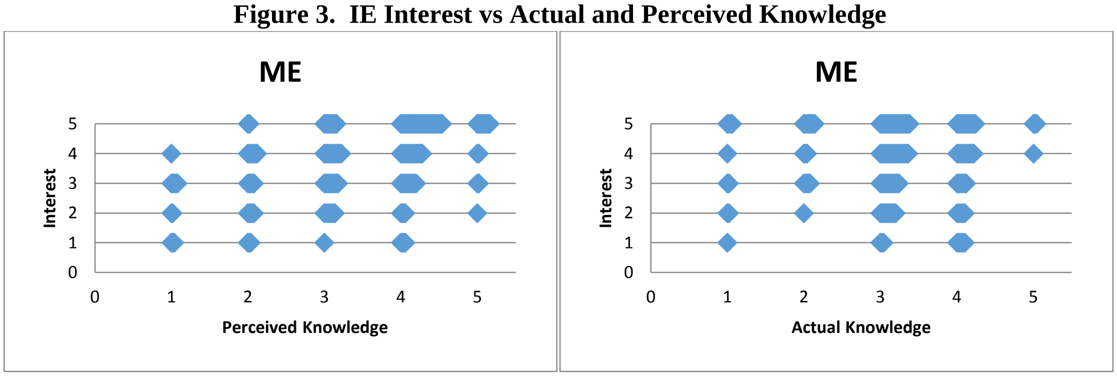


**Figure 4. ME Interest vs Actual and Perceived Knowledge**

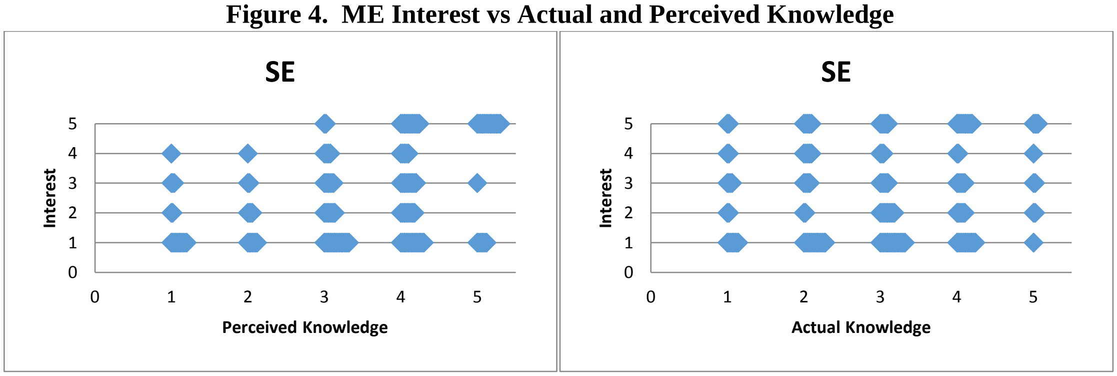


**Figure 5. SE Interest vs Actual and Perceived Knowledge**

Additionally, correlation coefficients were calculated and test of hypotheses were conducted to test for the absence of correlation. The correlation coefficients (Table 1) support the evidence from the graphs that there is little to no correlation between a student's interest in a major and their actual or perceived knowledge of that discipline. For the test of hypotheses, the standard null and alternative hypotheses of $\rho = 0$ and $\rho \neq 0$, respectively, were used. The results and p-values, of these test (Table 1) with sample size of n=138 to 150, depending on number of surveys where students answered both questions, show that statistically there is an absence of correlation in five of the relationships supporting the claim of no correlation. Only those for perceived knowledge for civil, mechanical, and software are statistically significantly different from zero. However the values of these Correlation Coefficients (0.39, 0.41, 0.41) are too low to indicate that perceived knowledge is the primary factor in a student's interest in an engineering discipline.

**Table 1. Correlation Coefficients**

| | *Perceived knowledge (p-value)* | *Actual knowledge (p-value)* |
|---|---|---|
| CE | **0.39 (< 0.01)** | 0.16 (0.05) |
| IE | 0.11 (0.22) | 0.13 (0.10) |
| ME | **0.41 (< 0.01)** | -0.02 (0.78) |
| SE | **0.41 (< 0.01)** | 0.14 (0.10) |

The lack of a correlation may be due to the small sample size, and these questions will continue to be asked on the introduction to engineering course surveys as part of the planned longitudinal study.

**Question 2: For those students who are interested in and knowledgeable about a specific engineering discipline, does the introductory course strengthen that interest?**

In this case, interest was determined by a student declaring a specific engineering major. They were determined to be knowledgeable about that particular discipline by scoring 3 or higher in the actual knowledge rating done by the faculty. In order to determine whether or not a student's interest in their declared major was strengthened, the sum of the difference in the interest scores (from question shown in Figure 1) between the initial and final surveys was calculated as shown in the equation below. A positive interest score indicates that the interest was strengthened by an increase in the interest in the declared major and/or a decrease in the interest in the other three majors.

$$Interest\ Score = (Final\ Interest - Initial\ Interest)_{declared\ major} + \sum_{i=1}^{3}(Initial\ Interest - Final\ Interest)_{other\ majors}$$

Civil Engineering

Of the 26 civil engineering majors at the start of the course, 15 were determined to be knowledgeable about the major. By the end of the course, eight of the 15 demonstrated a strengthened interest in civil engineering with a positive interest score, with the exception of one of the 8 students whose interest decreased in all four disciplines, and in fact this student changed major out of engineering. The score for two of the remaining students was zero, indicating that those students' interest did not change. The remaining 5 students scored a negative interest score. All 5 students reported a 5 in civil engineering in both surveys; they reported an increase in interest in one or more of the other disciplines in the final survey.

Industrial Engineering

There were four industrial engineering majors interested and knowledgeable in the discipline. The interest score for two was positive, one was a zero, and one was a -1. The initial interest score for all four was 5, and their interest in IE remained at a 5 throughout the semester. For the two students with a positive interest score, their interest in the remaining disciplines decreased in the final survey. The student who scored a zero had unchanged scores between her initial and final surveys. The student who scored a negative interest score, still demonstrated strong interest in IE between the two surveys; his interest in the other disciplines shifted slightly between the two surveys. Given the sample size of four for IE, no meaningful statements can be made.

Mechanical Engineering

35 students were determined to be interested in and knowledgeable about mechanical engineering. At the end of the course, 16 of the 35 demonstrated a strengthened interest in mechanical engineering with a positive score. Four students scored a zero, with 5s for ME and unchanged scores for the other disciplines on both surveys. One additional student scored a zero, but his interest at the start of the semester scored a 4 in three of the four disciplines; at the end of the semester, his interest was strong for CE, resulting in his change of major from ME to CE. The remaining 14 students' interest scores were negative. For most of these students, their interest in ME stayed constant at 5 for both surveys, and the negative score indicates a strengthened interest in one or more of the other disciplines. Only four of these students showed a decrease in interest in ME, scoring a 5 in the initial survey and a 3 or 4 in the final survey, and one of these students changed his major to SE.

Software Engineering

16 students were determined to be interested and knowledgeable about software engineering. At the end of the semester, six of these students demonstrated a strengthened interest in their major with a positive interest score. Four scored a zero, with their interest in software engineering remaining at a 5 through the course of the semester. The remaining six students scored a negative interest score. Most of these students' interest remained high for SE, but their interest in the other disciplines increased. However, two of the six students with a negative interest score changed their major out of SE.

**Question 3: For those students who are unsure about what specific engineering discipline to choose, are the students more likely to be interested in a specific engineering discipline at the end of the course?**

At the start of the semester, there were 49 students in the course who had not declared a major in one of the four engineering majors offered at Quinnipiac University, and were either undeclared engineering (32 of 49) or had a declared major in a subject other than engineering (17 of 49). All but one of the students who had a declared major in a subject other than engineering had no intention of ever majoring in engineering, and took the introduction to engineering course because ‘it looked interesting’ or ‘plan to work with engineers.’ Three of the students who started the semester as undeclared engineering majors did not complete the final survey. Therefore these 19 students were removed from the analysis of Question 3 leaving an overall sample size of 30 students, consisting of 1 non-engineering major and 29 undeclared engineering. At the end of the semester, only the one non-engineering major changed her major to undeclared engineering, and 11 of the undeclared engineering majors had changed their major to a specific engineering discipline. Given the extremely small sample size only qualitative analysis was performed.

For the remaining students who started the semester as undeclared engineering majors, most have indicated either a constant strong interest or an increase in interest in one of the four engineering disciplines offered at Quinnipiac. Only eight of the 30 students did not indicate an increase in interest in any of the four disciplines.

**Question 4: Does the introductory course increase students’ knowledge, actual and perceived, about the specific engineering disciplines?**

The introductory course increases the students’ knowledge, both their perceived knowledge, as well as their actual knowledge, about the specific disciplines as shown in Figures 6-9. In these figures, the students’ actual knowledge is plotted versus their perceived knowledge from both the initial survey and the final survey.

By the end of the term, after the students go through the introductory engineering course, the strong majority have a reasonably good knowledge about the four engineering disciplines. This is evident in the majority of the data points falling in the upper right quadrant of Figures 6-9 (Final) (the length of data point clusters represents the number of students associated with each data point).

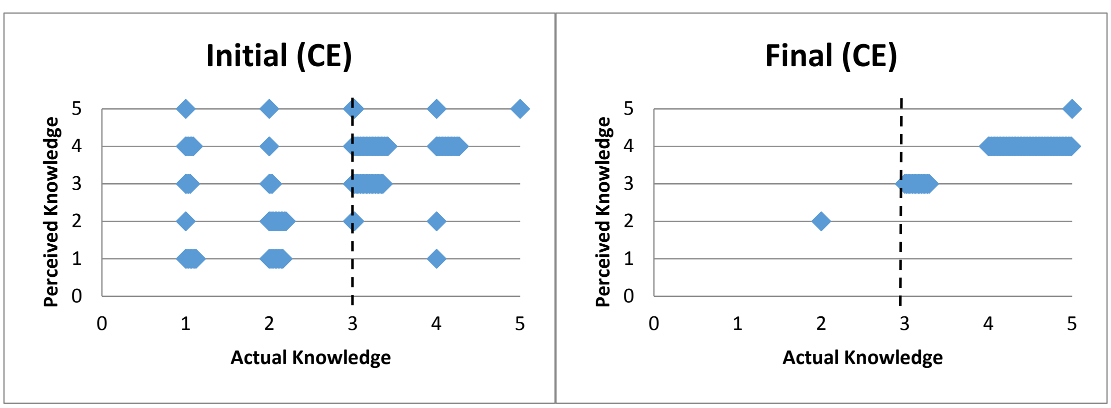


**Figure 6. CE Actual vs Perceived Knowledge – Initial and Final**

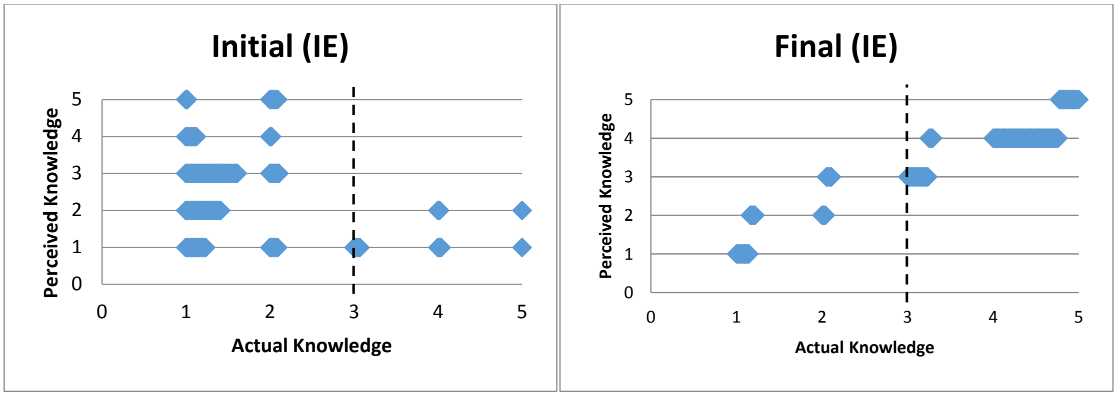


**Figure 7. IE Actual vs Perceived Knowledge – Initial and Final**

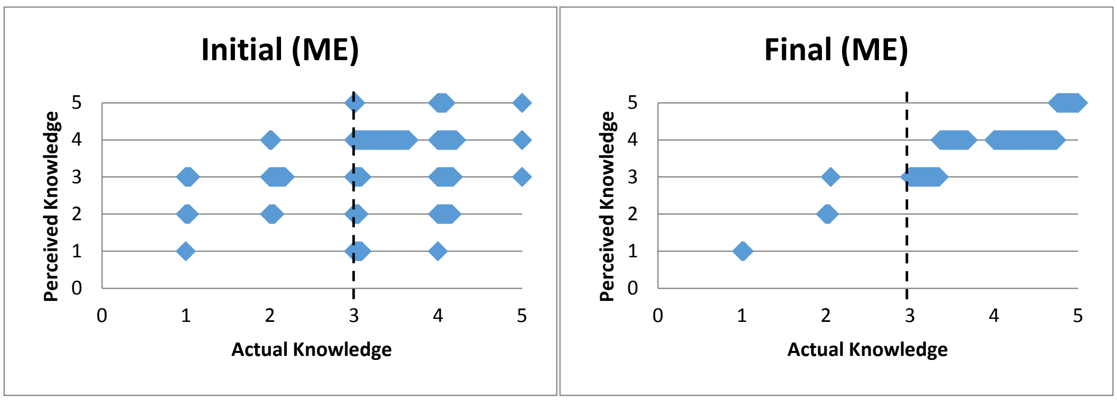


**Figure 8. ME Actual vs Perceived Knowledge – Initial and Final**

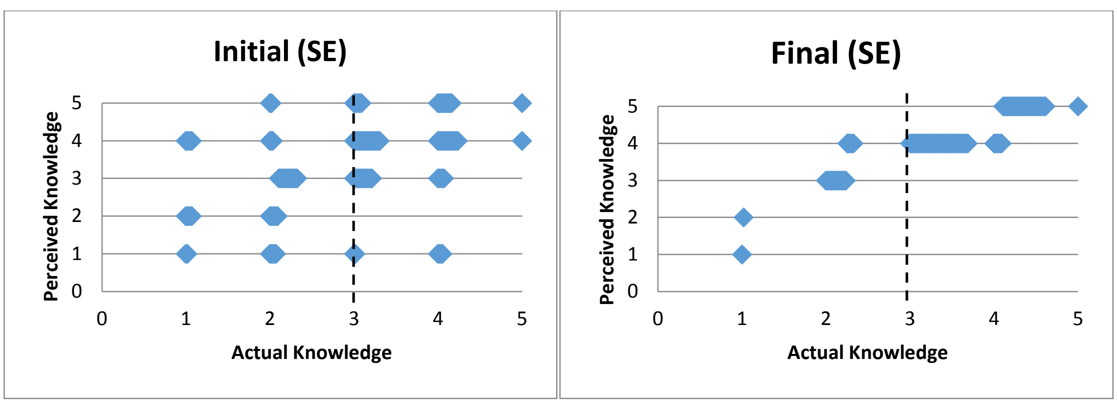


**Figure 9. SE Actual vs Perceived Knowledge – Initial and Final**

Additionally, paired t-test were performed to test for an increase in knowledge from the initial to final surveys. The average values and difference between the surveys (Table 2) support the evidence from the graphs that students increase both their actual and perceived knowledge of the disciplines. For the test of hypotheses the standard null and alternative hypotheses of $\mu_\Delta = 0$ and $\mu_\Delta \neq 0$, respectively, were used. The results of these tests and p-values (Table 2), for sample size n = 118 to 128, depending on how many students answered the corresponding questions on both the initial and final survey, show that statistically these increases in knowledge are significant.

**Table 2. Averages and Differences**

| | | *Initial* | *Final* | *Increase (p-value)* |
|---|---|---|---|---|
| *CE* | *Perceived knowledge* | *3.20* | *4.25* | ***1.05(<0.01)*** |
| | *Actual knowledge* | *2.83* | *3.41* | ***0.58 (<0.01)*** |
| *IE* | *Perceived knowledge* | *2.48* | *3.82* | ***1.34 (<0.01)*** |
| | *Actual knowledge* | *1.79* | *3.76* | ***1.97 (<0.01)*** |
| *ME* | *Perceived knowledge* | *3.33* | *4.06* | ***0.73 (<0.01)*** |
| | *Actual knowledge* | *3.11* | *3.70* | ***0.59 (<0.01)*** |
| *SE* | *Perceived knowledge* | *3.44* | *4.32* | ***0.88 (<0.01)*** |
| | *Actual knowledge* | *3.00* | *3.55* | ***0.55 (<0.01)*** |

## Conclusion

In this paper, we have investigated the effects of an introductory engineering course on student knowledge and their selection of a major. This paper serves as the first step in a longitudinal study that will compile data from multiple students across multiple years to investigate the whether initial knowledge and interest have a relationship with retention and satisfaction rates.

Many students enter the program with little knowledge on some of the engineering disciplines offered at Quinnipiac University. Some are cognizant of their unawareness. Throughout the semester, the students go through several lessons on each of the four disciplines as well as a hands-on project for each. By the end of the course, the strong majority of the students are aware of the nature of each of the four engineering careers. It can be stated as a statistically significant conclusion that the introductory course increases students' knowledge, both actual and perceived, about all four of the specific engineering disciplines offered at Quinnipiac.

Due to the small size in the current data set, we are not able to draw any other statistically significant conclusions. However, our analysis does provide support for some of our hypothesis. One such example is the course further strengthening the students' interest in the major of their choice. Evidence points to the fact that the course is helping students narrow their choice down to one major by the end of the term. However, this can only be stated as a qualitative statement and not a statistical conclusion. Nevertheless, such findings are encouraging and pave the way for further analysis in the near future upon collection of new data.

Our future work will be to continue to collect data on incoming freshman students, their initial interests, knowledge levels, and their progress and transformations throughout the first term. In addition, we plan to follow the students throughout the four years of engineering studies, quantitatively monitoring their performance, as well as qualitatively gauging their satisfaction with the chosen major. Once complete, the collection of this work can contribute to the literature and provide support for universities considering similar introductory engineering courses. As another future endeavor, it will be quite interesting to compare our results to the results of another institution. Given the fact that we are a mainly-teaching university, we can compare our results to that of s similar course but from a dissimilar institution, such as an R1 institution.

## References


1. Tinto, V., *Leaving College: Rethinking the Causes and Cures of Student Attrition*, Chicago, IL: The University of Chicago Press, 1987.
2. Marra, R. M., Rodgers, K. A., Shen, D. & Bogue, B., “Women engineering students and self-efficacy: A multi-year, multi-institutional study of women engineering student self-efficacy,” *Journal of Engineering Education, 98*(1), 27–38, 2009.
3. Marra, R. M., Shen, D., Rodgers, K. A., & Bogue, B., *Those that leave - Assessing why students leave engineering.* Paper presented at the American Society for Engineering Education, Honolulu, HI., 2007.
4. Johnson, M.J., and S.D. Sheppard. “Students Entering and Exiting the Engineering Pipeline-Identifying Key Decision Points and Trends.” In *2002 Proceedings of 32nd ASEE/IEEE Frontiers in Education Conference, Session S3C*.
5. Seymour, E., and N. Hewitt. *Talking about Leaving: Why Undergraduates leave the Sciences*, Boulder: Westview Press, 1997.
6. Marra, R. et al, “Leaving Engineering: A Multi-Year Single Institution Study,” *Journal of Engineering Education*, Vol. 101, No. 1, January 2012.
7. Knight, D.W., et al., “Improving Engineering Student Retention through Hands-On, Team Based, First-Year Design Projects,” in *2007 Proceedings of the 31st International Conference on Research in Engineering Education*.
8. Boettner, D., Byers, L, et al., “Teaching Design in Context,” Presented at the 2008 ASME International Mechanical Engineering Congress and Exposition, Boston, MA, November 2-6 2008.
9. Reap, J., Matusovich, M., Louis, R.A., “Chocolate Challenge: The Motivational Effects of Optional Projects in an Introductory Engineering Class”, *ASEE Annual Conference and Exposition*, June 10-13, 2012. San Antonio, Texas.


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# CAN WE USE A MATLAB APPLICATION TO IMPROVE STUDENT PERFORMANCE ON TRIGONOMETRY OF 3-DIMENSIONAL VECTOR PROBLEM SOLVING?

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Wentworth Institute of Technology

## Abstract

3-Dimensional vectors are a basic concept for electrical and mechanical engineering and computer science students. To improve the performance of students in classes such as statics, semiconductor materials, and computer graphics it is necessary to improve their performance on computing components of 3-dimensional vectors. We wrote a computer graphics, animated application in MATLAB to provide students with a method to improve their performance on computing 3-dimensional vector trigonometric components. MATLAB is a good choice for doing numerical computations and GUI interface writing; however, the object-oriented animated graphics were difficult to program. We assessed one group of first-year engineering students on 3-dimensional vector trigonometric computations who had access to the MATLAB application before the test. We assessed another group of first-year engineering students without access to the application (the control group). Using Student's t-test, the students' mean performance improved at a nearly, statically significance level.

## Introduction

Several faculty who teach mechanical and electrical engineering commented that students are sometimes weak in vector algebra [1,2,3]. This prompted us to do a preliminary survey of students in classes taught by one of us. We found that first-year students were weak in trigonometry. Students at University choose engineering either because they like to do it, for financial reasons or they want to contribute to humanity [4]. Preliminary data in this study and from teaching experience suggest that they have some weakness in vector mathematics which tends to discourage them from continuing in engineering. The literature on teaching vectors is limited to books on vector algebra, and chapters of books on engineering vector mechanics [5]. There are many books and papers on teaching secondary level mathematics[6]. Students who received problem-based instruction for two years demonstrated significantly higher mathematics achievement than traditionally instructed students—both in problem solving and in conceptual understanding [7]. We decided to take a problem-based learning (PBL) approach to increasing student performance in trigonometry of vectors. PBL has been used to teach medicine, engineering and other subjects [8,9]. PBL refers to teaching by having students use resources such as a computer to solve problems guided by an instructor [10].

Based on this data, we did two things. First, we wrote an animated graphical application in MATLAB to try to help students improve their trigonometry. Second we surveyed students who had access to the application and used a similar group of first-year students who didn't have access to the program as a control. The reason we used MATLAB is that it is a sequential language which we find easy to program in. Due to historical reasons, the animated graphics are object-oriented and somewhat difficult to use. MATLAB is derived from the sequential language, FORTRAN [11] which has been in use from 1956 to the present. MATLAB can be traced to Cleve Moler's thesis at Stanford [12]. MATLAB is one of the main products of The Mathworks which was founded in 1984. Mathworks now has approximately 1 million users [13]. Due to MATLAB's derivation from FORTRAN, it is a sequential language; however some of the animated graphics are object-oriented.

The main idea of this paper is to propose an animated graphical vector simulation to improve engineering and technology students' command of vector mathematics.

## Educational Aspects

Students were asked to solve for the components of a vector "by hand" and then compare their results to an animated problem solution tool. Animation is often used (e.g. WorkingModel software [14] to stimulate student interest. In the preliminary study, we animated a vector rotating and describing a unit circle. We tested the students initially on calculating the length of the shadow of a leaning tree. In the study with and without an application animating a rocket's altitude with various elevation angles, we tested the students on calculating the height of a building given a base-line and elevation angle.

In detail, a vector is a number with a direction associated with it. Freshmen students can remember how to calculate sums of numbers, but not sums of vectors in 2-dimensions[1,2,3]. This difficulty may be made worse in the case of vectors in 3-dimensions.

The main idea of this paper is to propose a 3-dimensional animated graphical vector simulation to teach engineering and technology students vector mathematics. By this we mean the ability to find the x, y, and z components of a 3-dimensional vector, and add 3-dimensional vectors by adding their components. See Appendix C for a flow-chart of the GUI for the simulation application.

## Methods

During the 2013 spring semester, one of us (Caserta) tested first, second, third and forth-year students in Engineering Technology, both students and advisees. These students were given a test of their ability to calculate the components of a vector. This involved calculating the horizontal component of a vector. The vector was the length of a leaning tree measured along the tree at the angle of elevation. The horizontal component was the horizontal length of its shadow with light coming vertically down from the sun (see Appendix A). (See Table 1 for a summary of their responses.) The purpose of this test was to do a preliminary assessment of a possible weakness in calculating the components of vectors.

During the 2013 fall semester, two of us (Ma and McCusker) taught first-year engineering students in Introduction to Engineering. Students were exposed to an animated horizontal component calculator application coded in MATLAB. All sections of Introduction to Engineering, including more than 125 students were tested. The vector component calculation test was administered to these engineering students. (See Figures 1 and 2 for a summaries of their responses.) This test assessed the first-year students since, in the earlier preliminary study, they seemed the weakest group. Furthermore, we thought that the first-year engineering students were at risk for failure in statics, control theory and computer graphics since calculating vector components is fundamental to learning these subjects.

At the end of fall 2013, one of us (McCusker) administered a second test to his students. In this test the students were asked to calculate a vertical component (height of a building), given the horizontal component (base line) and angle of elevation of the top of the building (see Appendix B). One section was given access before, but not during, the test to an animated, computer graphics altitude calculator coded in MATLAB and the other control group wasn't given access. (See Table 3 for a summary of their responses.)

At the end of fall 2014, one of us (Ma) administered a test to her students. In this test the students were asked to calculate a vertical component, given the horizontal component (base line) and angle of elevation of the vector and the length of a vector given the horizontal component. They were also asked to calculate a diagonal vector distance across the cube. One section was given access before, but not during, the test to an animated, 3-dimensioal computer graphics calculator coded in MATLAB. That section was tested before and after being given access to the software; thus they were both the control group and the group tested with access to the software. (See Table 4 for a summary of their responses.)

The tests did not record the gender or socio-economic status of the students.

## Discussion of Results

The preliminary results indicated that freshmen have some weakness in the analysis of vectors, particularly in the area of resolving vectors into components. This basic vector algebra is essential for applying vector algebra to problems in various engineering disciplines. Most of our University's students have reasons other than interest in vector mathematics for studying engineering (Caserta, Lind and Chedid, Spring 2011). So the low performance of freshman on vector calculations is understandable.

First year students' performance on a second vector trigonometry problem was graded A,B,C,D or F. A and B were correct, except B was the grade assigned for incorrect units. D answers showed awareness of the concept of "SOH CAH TOA." A grade of F was assigned if the student gave no answer. Numerically, A=5, B=4, C=3, D=2, and F=1. The results without the application are shown in Fig. 1. The average is 3.97. The results with the application are shown in Fig. 3. In Fig. 2, we see that there is a large improvement for students with access to the animated graphics application since the average is raised to 4.66. Using Student's T-test, we found the difference in the means significant at the P=0.05 level [15]. For the students taking the 3-dimensional test the difference of the means was significant at the P=0.08 level [15]. Thus the results were nearly significant, but did not attain the standard significance level of P=0.05.

## Conclusion

More study is needed to determine if a larger statistical sample of students will yield a greater difference in the ability of students to do 3-dimensional vector calculations. That is to say, a larger statistical sample of students might yield significance at the standard P=0.05 level.

## Acknowledgement

The authors would like to acknowledge the significant help in planning this research study rendered by Ray Nagem of Boston University, Robert Lind and Michael Werner of our University.

## References

[1] Ma, G., personal communication, 2013

[2] Lind, R., personal communication, 2012

[3] McCusker, J., personal communication, 2012

[4] Caserta, Frank, R. Lind, L.G.Chedid, Why do students at Wentworth Institute of Technology choose the Electromechanical Engineering Major?, ASEE Northeast Regional Conference, Spring 2011

[5] Beers and Johnson, 1997

[6] Brumbaugh, Ashe, Ashe and Rock, *Teaching Secondary Mathematics*, Lawrence Erlbaum Associates, Inc., Mahwah, New Jersey, 1997

[7] Posamentier, Hartman and Kaiser, *Tips for the Mathematics Teacher Research-Based Strategies to Help Students Learn*, Corwin Press, Inc. 1998, page 97

[8] Wood DF. Problem based learning. BMJ 2003;326:328-30.

[9] AK, S., The effects of computer supported problem based learning on students' approaches to learning, Current Issues in Education, 14(1)

[10] Vekli, Gulsah and Cimer, Atilla, Procedia - Social and Behavioral Sciences 47 ( 2012 ) 303 – 310

[11] Backus, John, IBM Systems Journal, 4(1):73-80

[12] Moler, Cleve, PhD Thesis, Stanford University, 1965

[13] Mathworks, http::www.mathworks.com/company/newsletters

/news_notes/clevescorner/dec04.html?s_cid:wiki_matlab_3 last accessed 3/2013

[14] MSC Software Corporation, *Working Model*, MSCSoftware, San Mateo, California, 2000

[15] Rickmers, Albert and Todd, Hollis, *Statistics*, McGraw Hill, New York, 1967

Table 1 Data

| | Name | Major | Before | After |
|---|---|---|---|---|
| 1 | student | Mechanical | 1.0 | 1 |
| 2 | student | Interdisplinary | 1.0 | 1 |
| 3 | Student | Mechanical | 0.0 | 0.5 |
| 4 | student | Mechanical | 0.0 | 1 |
| 5 | student | Interdisplinary | 1.0 | 1 |
| 6 | student | Mechanical | 0.8 | 1 |
| 7 | student | Interdisplinary | 1.0 | 0 |
| 8 | student | Computer | 1.0 | 1 |
| 9 | student | Interdisplinary | 1.0 | 1 |
| 10 | student | Mechanical | 0.0 | 0 |
| 11 | student | Mechanical | 0.0 | 0 |
| 12 | student | Mechanical | 0.0 | 1 |
| 13 | student | Computer | 1.0 | 1 |
| 14 | student | Mechanical | 1.0 | 1 |
| 15 | student | Mechanical | 0.5 | 1 |
| 16 | student | Electrical | 0.0 | 0 |
| 17 | student | Electrical | 0.0 | 1 |
| 18 | student | Mechanical | 0.0 | 0 |
| 19 | student | Mechanical | 1.0 | 1 |
| 20 | student | ElectroMechanical | 1.0 | |
| 21 | student | Mechanical | 0.0 | 1 |
| | | | | |
| | **Average** | □ | **0.54** | **0.73** |
| | **Sample standard deviation** | □ | **0.47** | **0.28** |
| | **Difference of the means** | □ | **0.19** | |
| | **P-value** | □ | **0.07** | |
| | **N** | □ | **20.00** | |

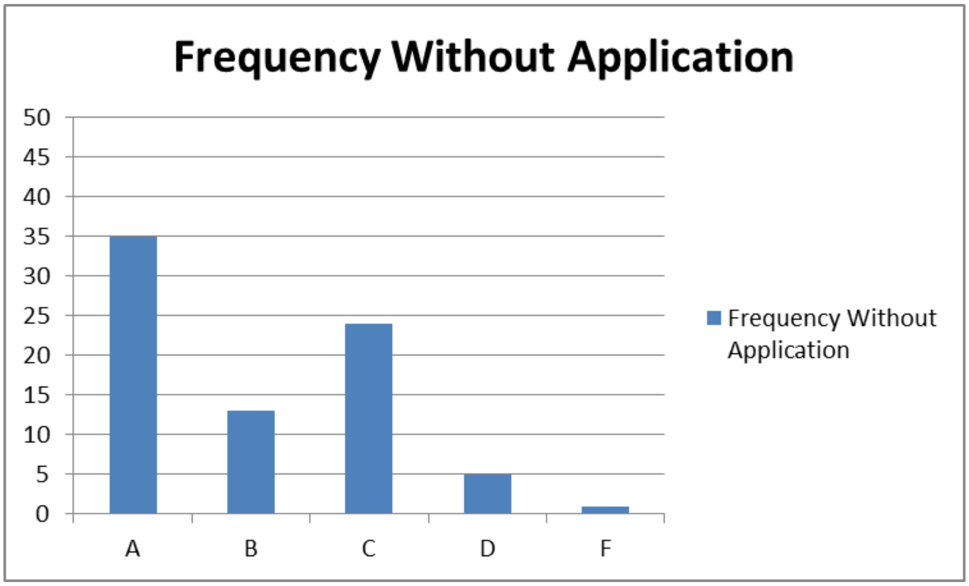



Figure 1 Frequency distribution without exposure to the application

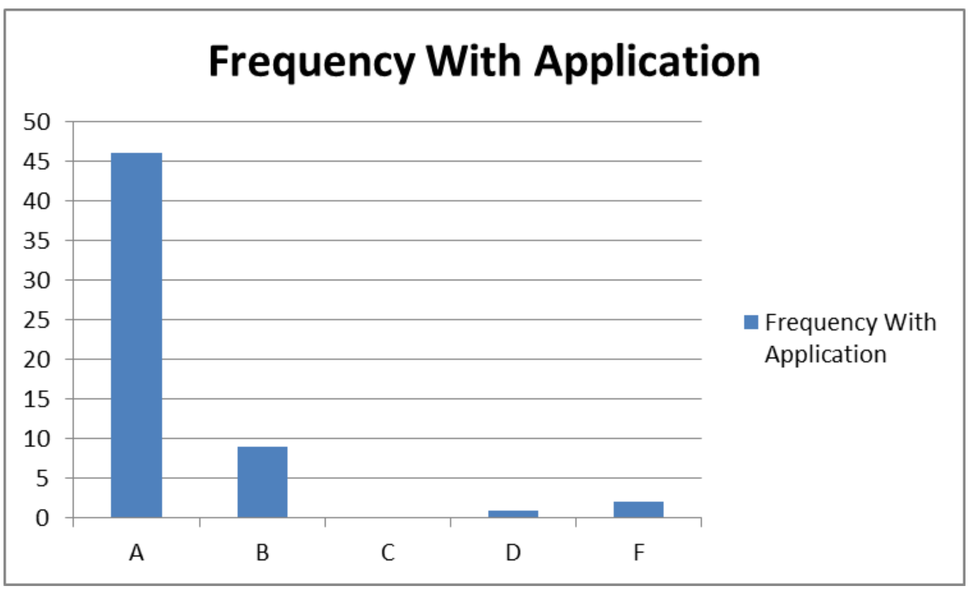
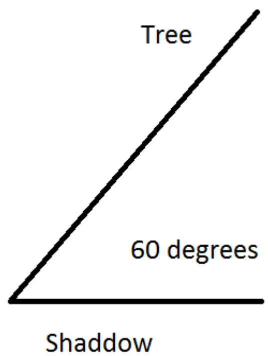



Figure 2 Frequency distribution with exposure to the application

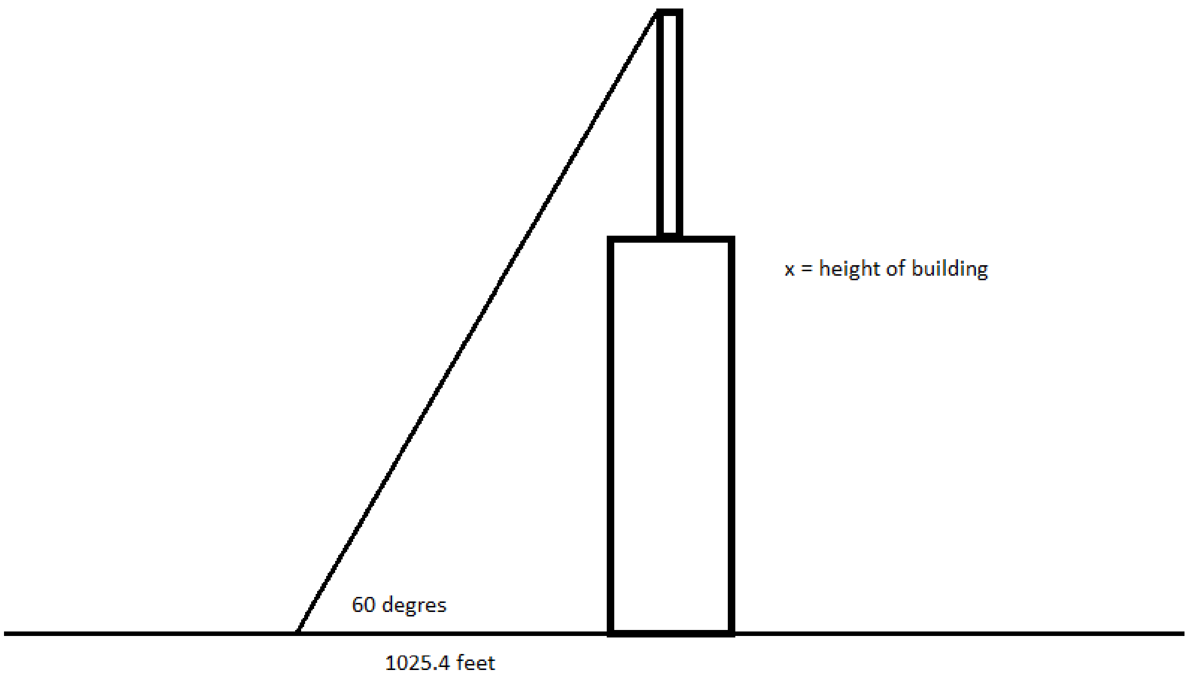
Appendix A Educational Research Question: Find the horizontal component of a vector given the magnitude and angle of elevation of the vector

A 1m tree is leaning at a 60 degree angle. The sun is directly above it. Find the length of its shadow.

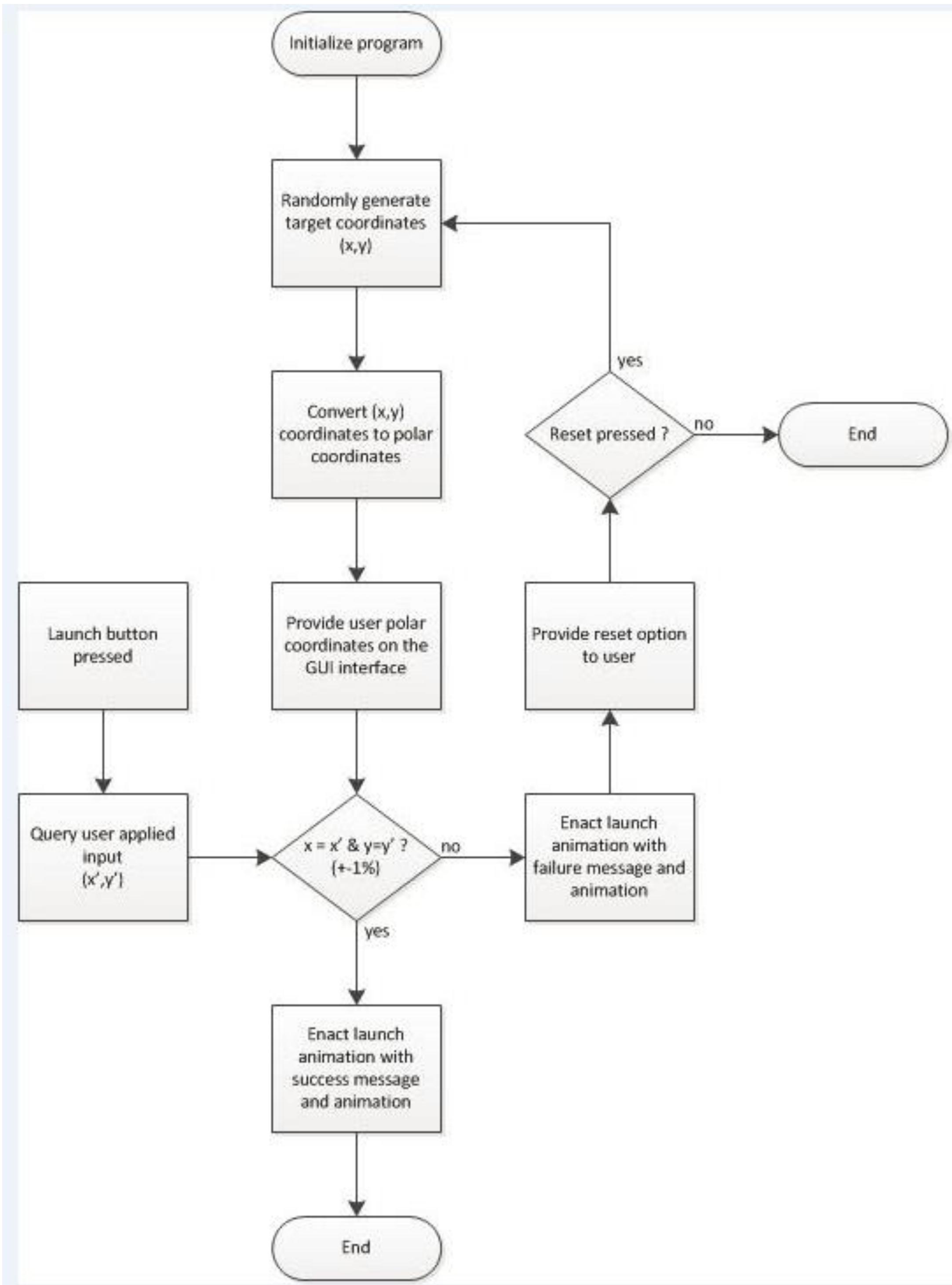


Appendix B Educational Research Question: Find the vertical component of a vector given its horizontal component and angle of elevation

A new international trade building has been built in New York City. An engineer sights the very top of the building from 1025.4 feet away at a 60 degree angle to the horizontal. Find the height of the building.



Appendix C – Flow Chart for Computer Animated Application GUI



Appendix D Test on Three Dimensional Vectors

Two of us (Ma and McCusker) conducted the following test:

Test on Three Dimensional Vectors

1. Person #1 sights a rocket at 45 degrees. The base line is 100m. Find the altitude of the rocket.
2. Person #2 sights a rocket at 45 degrees. The base line is 100m. Find the distance from the person to the rocket

# Student Collaborative Group Work on Advanced Course Materials in an Introductory Physics Course for Engineering Technology Majors

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## Abstract

We studied the effect of exposure to physics topics beyond the expected course level on students in an algebra-based General Physics course. General Physics is a required course of Engineering Technology and Computer Technology programs at Queensborough Community College (QCC). During the study, same instructor taught two sections of the same course. In the experimental section of the course the instructor formed collaborative/cooperative groups and assigned the groups to work on topics beyond the expected level of the course. Students explored the topics with applications to real life and solved more complex problems. They also presented some of their findings to the class. The control section of the course was taught with traditional lectures. We compared students' understanding of basic physics principles, their problem solving skills and attitudes towards physics and physics learning in both groups. In this paper we present the results of the analysis of the pilot implementation.

## Keywords

Physics education research, collaborative group learning, cooperative groups, problem-solving, engineering technology majors, learning attitudes.

## Introduction

Many college students regard physics as a very difficult subject. They often hesitate to take physics or change their career paths to avoid taking physics. To improve teaching methods, numerous faculty members are conducting rigorous research on how students learn physics[1-4]. In fact, physics departments of more than 20 well known universities offer PhD degree programs in physics education research[5]. As a result, the physics education research field has produced a large volume of literature over the past decade. Many physics faculty are aware of these findings and many adapt these discoveries in their classrooms[6-12]. It is very difficult to determine the best method of teaching that improves students' comprehension of physics concepts and problem solving skills. Many published findings on physics education research cannot be generalized to the entire student body of the country. Depending on students' educational background and experience, teaching techniques and methods should be modified. For example, even though the topics covered and textbooks used by many universities to teach college physics are the same, teaching methods successful in a highly ranked university may not work at a community college setting. The general aim of this study is to find teaching methods that improve physics learning of community college level students.

One of the new learning strategies that researchers tested and many adapted in their classrooms is collaborative learning. Collaborative learning is a case in which two or more people attempt to learn a course content together[13]. When the cooperation is emphasized more than the competition between group members, such collaborative groups are referred to as cooperative groups. In cooperative learning members of a group pursue a common task, share information with other members and provide feedback to each other. All members of the group depend on and are accountable to each other. Many researchers reported that collaborative learning helped students to be active participants of the course and improved students' course performance[13-15].

In general, cooperative group problem solving in physics courses has been shown to give positive results[16-18]. For example, Heller et al[16] showed positive problem-solving gains when cooperative groups were formed in recitations and context-rich problems were assigned to students. They have also tried the same technique at a local community college in a sophomore-level modern physics course. How effective it would be for our population remains unanswered. Would it work if it is tried out in a freshman level course, with a diverse student population, with student cohort of the year of 2014 rather than 1992?

In this paper we investigate the impact of cooperative work on advanced course materials on students' conceptual understanding, problem-solving ability and attitudes on physics and physics learning. Students spent time in groups outside of class exploring basic physics concepts of topics beyond the scope of the course material, found and solved real-life problems related to their topics. We used students' class tests, final exams, concept inventories and attitudinal surveys to evaluate the impact.

## Intervention

*Course Description:* During this study we used two sections of the same physics course, General Physics I (PH-201). It is a first semester of a two semester-long introductory physics course with algebra prerequisite for Engineering Technology and Computer Technology majors at Queensborough Community College (QCC). QCC typically offers 4 lecture sections of the course with about 30 students in each section. Weekly distribution of course hours is 2.5 hours for lecture, 1 hour for recitation and 2 hours for lab. The official textbook for the course was Serway & Vuille "College Physics".

The second author (S. Dehipawala) was the lecture instructor for two sections of the course; one section served as a control group and the other as an experimental group. In both sections weekly homework assignments consisted of end-of-chapter textbook problems. The course had three written class tests, several quizzes and one final exam. After homework collection solutions were posted on the course web-page. Collected homework were graded and returned back to students during next class meeting. Students of both experimental and control groups had access to the posted solutions. Three course tests and final exams were composed of several physics problems requiring calculations. Same homework assignments, tests and final exams were given to both groups. The final exam was cumulative.

Students in the control section of the course were taught with traditional lecture instructions. During the lectures physics concepts were introduced with lectures, demonstrations and video clips. Example problems were solved during each lecture with participation of students.

Students were encouraged to come up to the board and solve problems. Other students were given a chance to challenge the solutions and provide their inputs. Students were free to study together or discuss course material. But each student was evaluated separately based on their performance on class tests, quizzes and final examination.

*Collaborative Group Work:* The experimental section received similar instructions on the same topics each week but in addition to regular class work students were asked to work in collaborative groups on additional assignment. Five collaborative student groups were formed. Each group consisted of 4-5 students. Student groups were assigned special topics in physics (Table 1). Students in the group were required to study the assigned topic in depth beyond the scope of the class and then later present their work to the entire class. As a group, students had to gather more information, find more advanced real-life applications of their assigned topic and solve more complex problems. Since physics courses cover properties of matter, types of energies and their interactions, students could find many examples in everyday life where physics principles are used. All members of the group had to share their findings with other members. They would meet with the instructor to discuss their progress and get suggestions (for about 10-15 minutes each week). Closer to the end of the semester a portion of lecture time was used for student presentations.

| Collaborative Groups | Assigned topics | # of students in the group |
|---|---|---|
| Group 1 | 1-D motion, Kinematics | 4 students (all male) |
| Group 2 | Projectile motion | 4 students (1 female) |
| Group 3 | Newton's law of motion-Friction, Free body diagram, Mechanical Equilibrium | 4 students (1 female) |
| Group 4 | Circular motion-Gravitation | 4 students (all male)[1] |
| Group 5 | Work, Energy, Conservation of Energy | 5 students (all male) |

Table 1: Collaborative groups and assigned topics. [1]Group 4 started with 5 students, one student didn't contribute at all and is not counted.

The group work and presentations were counted as 20% of the course grade (15% for the presentations and 5% for the work they submitted). The groups were given about two-month time to work on their topic in addition to regular class requirements. Students were required to learn the basic physics concepts related to the topic, and then perform an in-depth investigation of the topic with real life applications and work on numerous problems related to the topic. Students within each group were asked to actively participate and work on his/her own part of the topic. After 8 weeks of preparation each group was asked to present their findings to the rest of the class in a 15-20 minutes presentation. The other students in the class were given chance to participate in the evaluation process and received the opportunity to ask questions to the group. To receive full 20% credit for the collaborative work, all members of the group had to know the material and be prepared to present any part of their work at the final presentation time. If one student failed the grade of other group members would be affected as well. Therefore to receive full credit students had to make sure other members of the group knew the material (thus, creating positive interdependence, a key element of cooperative learning[13]).

The topics assigned to the groups are shown in Table 1. The instructor formed the groups based on students' consistent sitting pattern in the classroom that had a studio-type setting.

## Evaluation

*Evaluation Tools:* To evaluate students' physics problem solving mastery we used class tests and the final exam. Both were composed of a set of open-ended physics problems. Neither contained multiple-choice or conceptual questions. The first two class tests were administered before the intervention. In order to evaluate students' conceptual gains we have administered pre and post Force Concept Inventory[19] (FCI) test. The test is widely used to evaluate students' conceptual understanding of Newtonian physics, with an emphasis on evaluating students' common misconceptions. Pre- and post-tests in science learning attitudes were measured using Colorado Learning Attitudes about Science Survey[6] (CLASS). We collected a demographics survey as well. The experimental group filled out a survey on their experience in the Collaborative Group Project.

*Student Population:* In the evaluation we included only those students who attended the class till the end of the semester and took the final examination. This pilot study was conducted in the Fall, 2014 semester. The experimental and control groups had 21 and 29 students, respectively. QCC is an open-admission community college located in one of the most diverse places in the country (Queens); this diversity is reflected in our student population as well. 7 students of the experimental group population identified themselves as Asian, 7 as Hispanic/Latino, 1 as African-American, 5 as two or more races and only 1 as White. In the control group 9 students identified themselves as Asian, 4 as Hispanic/Latino, 1 as African-American, 6 as two or more races and 5 as White. Both sections had only 2 female students.

*Conceptual gains:* Pre and post FCI test analysis shows that both experimental and control groups were same in terms of their initial conceptual understanding. Both groups had similar gains. Initial FCI scores of the experimental group (*Mdn* = 5.5% correct responses) did not significantly differ from the control group result (*Mdn* = 5.5% correct responses) based on two-tailed Mann-Whitney U-test, $U = 286.00$, $z = -0.433$, $p = 0.665$. Post-test FCI scores of experimental group (*Mdn* = 32% correct responses) did not significantly differ from the control group's scores (*Mdn* = 30.5% correct responses) either (two-tailed Mann-Whitney U-test, $U = 253.5$, $z = -1.07$, $p = 0.286$).

Average normalized FCI gain $G$ was determined using the following formula:

$$G = \frac{\text{postscore\%} - \text{prescore\%}}{100 - \text{prescore\%}}$$

Mean FCI gains of the experimental and control groups were 0.36 and 0.21, respectively ($p = 0.282$, $r = -0.15$). The effect size ($r = -0.15$) indicates very small impact on the experimental group that is due to the intervention. Effect size was determined by the ratio of z-score to the square root of total number of students[20].

*Physics problem-solving gains:* As a measure of students' initial problem solving level before the implementation of the intervention we used students' scores on the first two class tests of the course. We used final examination scores as a measure of students' problem-solving ability at the end of the intervention. Note that both class tests and the final examination were comprised of a set of physics problems and were scored based on how well students can solve those problems (applying appropriate physics laws to the described situation, setting up the equations correctly, solving equations and evaluating the solution).

Since Mann-Whitney U-test p-values are bigger than 0.05 for all the examinations, the groups were equivalent at the start of the study and remained the same by the end. Thus, the intervention neither harmed nor benefited the students overall problem-solving performance.

| Exp. N = 21 Contr. N = 29 | First Test | | Second Test | | Third Test | | Final Exam | |
|---|---|---|---|---|---|---|---|---|
| | Median (out of 100) | | Median (out of 100) | | Median (out of 100) | | Median (out of 100) | |
| | Exper. 51 | Control 45 | Exper. 48 | Control 45 | Exper. 45 | Control 39 | Exper. 45 | Control 44 |
| U-statistic | 302.5 | | 350.0 | | 259.0 | | 305.0 | |
| z-score | -0.04 | | 0.9 | | -0.89 | | 0.01 | |
| p-value | 0.97 | | 0.37 | | 0.37 | | 0.99 | |
| Effect size | | | | | r = 0.13 | | r = 0.001 | |

Table 2: Comparison of midterm and final examination problem-solving performance of the groups.

We also examined Collaborative Groups' final exam performance on problems directly related to their assigned themes. Would the groups' performance on those topics be better than performance of the rest of the class? The final exam structure allows us to do the comparison since 5 problems of the final (out of 6) corresponded to the individual collaborative group topics. All the collaborative groups except Group 4 did either a better job (groups 1 and 3) or an equivalent job (groups 2 and 5) than the rest of the experimental section on those problems (Table 3). Note that Groups 1 and 3 not only did better, but outperformed others with big difference (e.g., Group 3 median score on their problem was 8/10, whereas the median score for the rest of the class was 3.5/10). Based on the first class test scores (before the intervention) for groups (Table 4), the better performance of Group 1 was expected since they were better prepared students on the first place. But for Group 3 the big difference could be attributed to the intervention since they were low-scoring group at the beginning. A likely reason why Group 4 did worse than others is that the group consisted of low-ability students (the median Group 4 score on the first midterm exam was 29 while for the rest of the class had a median grade of 54).

| | Final exam pr. 1 | | Final exam pr. 2 | | Final exam pr. 3 | | Final exam pr. 5 | | Final exam pr. 4 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Grp. 1 | The rest | Grp. 2 | The rest | Grp. 3 | The rest | Grp. 4 | The rest | Grp. 5 | The rest |
| Median score | 8 | 4 | 6 | 5 | 8 | 3.5 | 0.4 | 4.2 | 3.5 | 4 |

Table 3: Comparison of collaborative groups' performance on final exam problems directly related to their topic. All the scores are out of 10 points (partial credit was given for partially correct solutions).

| | Test 1 scores (out of 100) | | | | | Final exam scores (out of 100) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Grp. 1 | Grp. 2 | Grp. 3 | Grp. 4 | Grp. 5 | Grp. 1 | Grp. 2 | Grp. 3 | Grp. 4 | Grp. 5 |
| Medians | 66.5 | 50.4 | 39.5 | 29.5 | 65.5 | 63.5 | 42 | 48 | 24 | 44 |

Table 4: Comparison of collaborative groups' performance on the first test (before the intervention) and the final exam.

All in all, in terms of gains in conceptual understanding and problem-solving, the intervention did not affect the experimental group negatively, and there is some evidence that it helped few groups to perform better on the problems related to their topic.

*Learning Attitudes about Science (CLASS survey):* In this subsection we present the evaluation of the impact of the intervention on students' attitudes towards learning physics. CLASS[5] is widely used instrument designed to measure student beliefs about physics and learning physics. In the survey students are asked to respond on a Likert-like (5-point strongly agree to strongly disagree) scale to questions such as: "Learning physics changes my ideas about how the world works". The survey has overall 42 questions. It has been shown that traditional teaching practices result in the overall decrease of CLASS scores[5].

Following the survey administration recommendations we have merged Strongly Agree and Agree responses (as well as Strongly Disagree and Disagree items). The survey is scored is by comparing students' responses to responses given by physicists (experts). We have calculated the average percentage of students' responses that are in agreement with the experts' responses as well as percentage of responses that are opposite to what experts choose. Such responses are noted as Favorable and Unfavorable, respectively. As shown in Table 5, the experimental section outperformed the control group and showed higher shifts almost doubling the percentage of favorable responses. Thus, the intervention had significant positive impact on students' beliefs about physics and learning physics.

| | Pre Fav. % | Post Fav. % | Pre Unfav. % | Post Unfav % |
|---|---|---|---|---|
| Experimental | 26 | 41 | 42 | 30 |
| Control | 23 | 29 | 40 | 37 |

Table 5: Percentages of CLASS favorable and unfavorable responses and their shifts.

| N exp. = 20<br>N contr. = 25 | | PI | | RWC | | PS - G | | PS - C | | PS - S | | SM/E | | CU | | ACU | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | pre | post | pre | post | pre | post | pre | post | pre | post | pre | post | pre | post | pre | post |
| Exp. | fav | 7 | 53 | 9 | 41 | 11 | 19 | 18 | 28 | 18 | 27 | 48 | 36 | 41 | 23 | 29 | 27 |
| | unfav | 63 | 14 | 54 | 21 | 64 | 43 | 59 | 41 | 53 | 37 | 21 | 31 | 28 | 51 | 42 | 45 |
| Cont. | fav | 22 | 29 | 31 | 10 | 33 | 32 | 44 | 51 | 20 | 20 | 20 | 21 | 13 | 8 | 21 | 14 |
| | unfav | 48 | 29 | 40 | 49 | 35 | 32 | 19 | 14 | 44 | 41 | 39 | 30 | 44 | 69 | 35 | 59 |

Table 6: Percentages of favorable and unfavorable responses for the following CLASS categories: PI = Personal Interest (do students feel a personal interest/connection to physics?); RWC = Real World Connections (seeing the connection between physics and real life); PS - G = Problem Solving General; PS - C = Problem Solving Confidence; PS - S = Problem Solving Sophistication; SM/E = Sense Making/Effort (for me [the student], exerting the effort needed towards sense-making is worthwhile); CU = Conceptual Understanding (understanding that physics is coherent and is about making sense, drawing connections, and reasoning not memorizing. Making sense of math) ; ACU = Applied Conceptual Understanding (understanding and applying a conceptual approach and reasoning in problem solving, not memorizing or following problem solving recipes).

We examined the groups' responses to known robust CLASS sub-categories as well. The results are summarized in Table 6. The most striking positive differences for the experimental group were in the Personal Interest and Real World Connections categories. Surprisingly noticeable negative shifts appeared in the Conceptual Understanding category.

*Student feedback:* Students also filled out a survey on their experience in collaborative group work. They rated their overall experience in the collaborative group project very highly (Figure 1). Figure 2 shows correlations between the students' first midterm scores and student

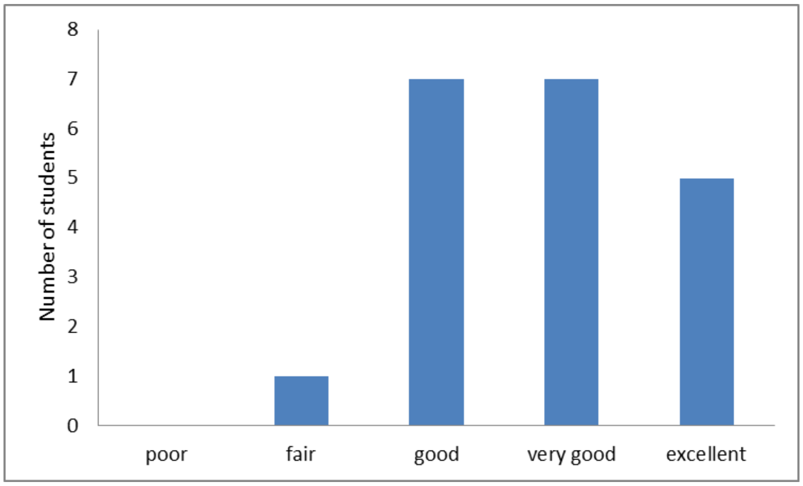


Figure 1: Students' rating of their overall experience with collaborative work for the class.

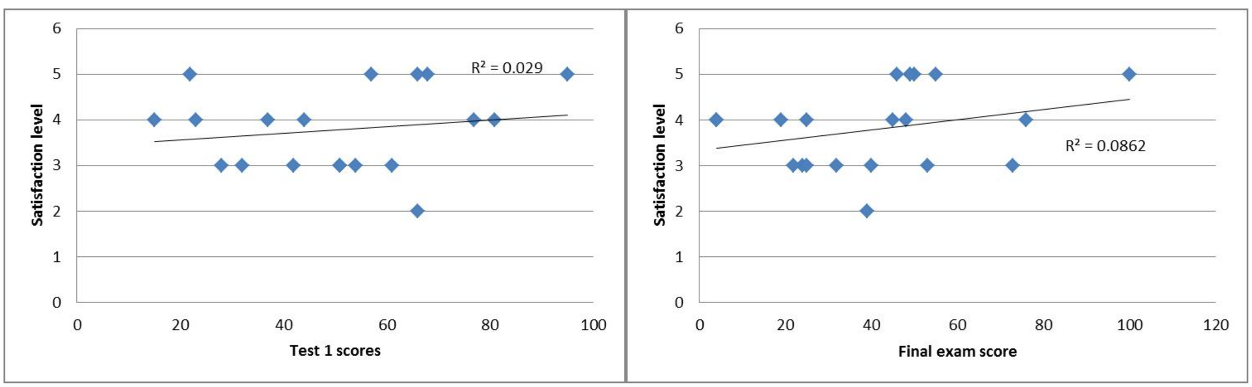


Figure 2: First class test and final exam scores versus satisfaction level, from Poor (level 1) to Excellent (level 5).

satisfaction ratings as well as between final exam scores and satisfaction rating. They show that both low-performing and high-performing students are equally likely to give high satisfaction rating for their experience in collaborative group project. Few representative answers to the remaining survey questions are provided in tables 7 and 8. The frequent mention of teamwork and how much they have learned from group members indicate that in most of the cases we had true cooperative groups, where group members were cooperating and helping each other. However the groups were not ideal since there were complains about slackers in the survey responses (Table 7, responses to Question 3).

| Q2: What do you like about collaborative work? | Q3: What do you dislike about collaborative work? |
|---|---|
| It was okay | Nothing at all |
| It helps built character | Sometime people won't do the work |
| The teamwork | Not everybody do the same work |
| It help improve grade | Some are lazy only want to learn from others and no contributions |
| Can get help from others | None |
| Well, that you can learn different technique from the peer student. Sometimes student can explain better than instructor | When nobody can figure out a problem |
| Everyone participates | Hard to find time for everybody to free |
| I could discuss about/I don't know or confused about more freely with other students than the instructor | Others don't work |
| Learning about problems | Sometimes people don't put their weight |
| I like to work with group | Not all work same way |
| It allows us to work together and correct mistakes | Relying on others |
| Have time to discuss and learn new things | If you work with group you kind of lazy |
| Everyone feeds off of each other, and you end up learning more when you heard from different people | Working on problems that were not taught well |
| Its great. You learn lot more from others | Time management. Everyone has different schedule |
| We learn from each other | Nothing |
| Its easier to work on | Sometimes work load is on one student only. Others don't do the work |
| I like working with people. It gives everybody something to do and if you don't know something others will help | Nothing |
| It gives us time to learn from each other | Always need to go to other class |
| More comfortable to work with friends | Nothing. It is good |
| Others motivate me. | Have to cooperate with people |

Table 7: Excerpts of student responses to the collaborative group project survey.

*Challenges of implementation*: Some students were not used to work with others. At the beginning they were reluctant to participate in group projects. But they were given no other choice than to work as a group. Many students were complaining about the lack of a common time to meet. This is challenging because all students are commuting from their homes and have different class schedules. The instructor requested students to utilize e-mails or Skype in the group-work. At the beginning some students complained about doing most of the work and not receiving much cooperation from others.

## Summary

Preliminary results of our pilot implementation show that although students' overall final exam grades and conceptual learning gains were equivalent between the treatment and control groups, at least few collaborative groups outperformed the others on final exam problems related to their assigned topic. There was a striking difference in students' physics learning attitudes with experimental group showing significant positive shifts. Surveys showed that students from all-performance level enjoyed the experience and found it useful (no "poor" rating and only one "fair" rating). We would like to explore how our results might change if more topics and longer preparation times are given to the class. We are also planning to conduct further analysis on what factors contribute to forming well-functioning collaborative groups in introductory physics courses at community college settings.

| **Q4: How did the collaborative group work aspect of this course help you better understand the course material?** | **Q5: In addition to learning the content of the course, what other skills did you learn/acquire through the collaborative group work?** |
|---|---|
| Because classmates can help you | How to do better research |
| It help me to get better understanding | How to solve different things |
| They help me with formulas | I learned momentum |
| Everyone work together | Helping needy one |
| It didn't | Communication skills, being able to work other type of people |
| Not lazy | Power point |
| When I do an exercise I can go with friend to compare | Teamwork |
| We help each other to solve problems | How physics works in everyday life |
| I could understand better because when I had to explain something to others it became clear to me also | How to work as a team |
| Help me understand the material little more | Care about others |
| You are under pressure to work on problems | Appreciate other ideas |
| It is easier to find how to do the work | Measurement in the lab |
| Sometimes when I don't understand the lesson, a group member can teach me in less complicated way. | How to memorize a formula |
| We learn from each other | Nothing |
| Yes they did. I didn't know some formula to use, they help me | Learn more about my team |
| It make me think more logically about problems | How to communicate |
| Open about physics | How to learn from one another |
| Get new ideas from others | Feelings of others |
| You get better sense about physics from others | |

Table 8: Excerpts of student responses to the collaborative group project survey.

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## References

1. Redish, E.F. and Steinberg, R.N. "Teaching physics: Figuring out what works," *Physics Today* , 52, 24-30 (January 1999).
2. Redish, E. F. **"**Building a science of teaching physics," *Am. J. Physics*, Vol. 67, 562-573 (July, 1999).
3. Voltaire Mallari Mistades, How Do Education Students Learn Physics? US-China Education Review B 4, 457-466 (2011).
4. Elby, A. "Helping physics students learn how to learn. American Journal of Physics," 69, 54-64 (2001).
5. http://en.wikipedia.org/wiki/Physics_education#Goals_of_physics_education_research_.28PER.29 (2014)
6. Perkins, K. K., Adams, W. K., Pollock, S. J., Finkelstein, N. D., and Wieman, C. E. "Correlating student beliefs with student learning using the Colorado learning attitudes about science survey," Proceedings of the 2004 Physics Education Research Conference, AIP Proc, No. 790 (2004).
7. McDermott, Lillian C. and Redish, Edward F. "Resource Letter: PER-1: Physics Education Research". *American Journal of Physics* **67** (9): 755–767 (1999).
8. Beichner, R., Bernold, L., Burniston, E., Dail, P., Felder, R., Gastineau, J., Gjertsen, M. and Risley, J. "Activity based collaborative study. Case study of the physics component of an integrated curriculum," Phys. Educ. Res., Am. J. Phys. Suppl. 67 -74 (1999).
9. Henderson, C, and Dancy, M. H. "Impact of physics education research on the teaching of introductory quantitative physics in the United States," Phys. Rev. Spec. Top-Phys. Educ. Res. 5, 3-9 (2009).

10. Hake, R. R. "Interactive engagement versus traditional methods. A six thousand student survey of Mechanics test data for introductory physics courses," Am. J. Phys. 66, 64-74 (1998).
11. Foster, T., Heller, P. "Problem solving labs at the University of Minnesota. Context rich problems," AAPT Announcer 26 (2),79 (1999).
12. Etkina, E., Gibbons, K., Holton, B. L., Horton, G. K. "Lessons learned: A case study of an integrated way of teaching introductory physics to at-risk students at Rutgers University," Am. J. of Phys., 67(9), 810-818 (1999).
13. Prince, M. "Does active learning work? A review of the research," J. Engr. Education, 93(3), 223-231 (2004).
14. Felder, R. M. and Brent, R. "Effective Strategies for Cooperative Learning." *J. Cooperation & Collaboration in College Teaching*, *10*(2), 69-75 (2001).
15. Gilley, B. H. & Clarkston, B. "Collaborative testing: Evidence of learning in a controlled in-class study of undergraduate students," J. Coll. Sci. Teach. 43(3), 83-91 (2014).
16. Heller P. and Hollabaugh, M. "Teaching problem solving through cooperative grouping. Part 2: designing and structuring groups," Am. J. Phys. 60(7), 637-644 (1992).
17. Sahin, M. "Effects of problem-based learning on university students' epistemological beliefs about physics and physics learning and conceptual understanding of Newtonian Mechanics," J. Sci. Educ. Techn. , 19, 266-275 (2010)
18. Duch, B. "Problem-based learning in physics: the power of students teaching students," J. Col. Sci. Teach. 25(5), 326-239 (1996).
19. Hestenes, D., Wells, M., and Swackhamer, G. "Force Concept Inventory," Phys. Teach. 30, 141-158 (1992).
20. Rosenthal, R. "Meta-analytic procedures for social research", 2nd ed.. Newbury park, CA: Sage, p. 19

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# Can Real-life Projects in Engineering Classes Result in Improved Interest and Performance in Clean Energy Careers?

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## Abstract

With funding from the Massachusetts Clean Energy Center, Northeastern University has been offering the Early College Experience (ECE) program to Boston Public high school seniors with the goal of increasing their interest in Clean Energy careers. The ECE program has provided high school students the opportunity to take a college-level Engineering Design course that covers the same content as that covered in the Northeastern University College of Engineering's freshman design course. The differences between the ECE program and the Northeastern freshman design course are that the ECE program offers the Engineering Design course over two semesters (rather than one), and a final design project for ECE students is a real life clean energy service project (an energy audit of their school rather than a hypothetical sustainable home design project). Separately, ECE students have received additional tutoring supports from college students to assist them with their rigorous high school mathematics coursework. A mixed-methods external evaluation has found that students participating in ECE have demonstrated increased interest in Clean Energy careers after participating in ECE, increased content knowledge, and increased confidence succeeding in college. Analysis of grading data shows that the 2014-2015 cohort of students have demonstrated improved scores compared to previous cohorts of ECE students.

## Keywords

K-12 and Pre-College Engineering, Clean Energy, First Year Programs, Service Learning, Real life project

## Introduction

Funded by the Massachusetts Clean Energy Center, the Early College Experience (ECE) program at Northeastern University has been offered annually to three different cohorts of students annually since 2012. The goal of ECE has been to increase interest in Clean Energy careers for selected cohorts of Boston Public School (BPS) High School students. Annually for the past three years, Northeastern has selected students who are taking advanced mathematics courses in high school to participate in the ECE. The ECE has offered participating students the opportunity to take the freshman Engineering Design course at Northeastern University and to receive tutoring and support for the Advanced Placement (AP) calculus course they are taking in their high school.

## Background

*Course Description*

The Engineering Design at Northeastern University is a 4-credit freshman engineering course that follows the engineering design cycle as students develop a minor design project, a deconstruction project, and a major design project. Students are also taught to use engineering tools, such as orthographic projection, AutoCAD, and SolidWorks.

The goals of this course are to (1) introduce students to the engineering profession and creative engineering problem-solving through design projects, presentations, and activities (2) familiarize students with the various engineering disciplines and their interrelationships (3) provide historical perspective on engineering design processes, successes, challenges, and failures and their influence on contemporary society (4) inspire and instill an appreciation for the engineering profession, its ethics, and practices.

The Engineering Design course offered to the ECE high school students has covered the same content as the college course described above but the course was modified in two important ways. First, the time over which the course was offered was extended over two semesters for the high school students, whereas it was provided in one semester for the college freshmen. This change was made to accommodate students' schedules because each of the selected high school students were taking a full, rigorous high school course load. Secondly, for the 2014-2015 cohort of students, the major design project subject matter was a clean energy real-life design project, whereas college students and previous cohorts of ECE students had been assigned a hypothetical sustainable home design project.

The 2014-2015 cohort of participating ECE high school students engaged in a year-long, real-life project to design improvements in energy efficiency for their high school (also referred to as an energy audit). The students worked in partnership with the engineering firm, Energy Engineering & Design (EEED). EEED supplied measurement tools, engineering drawings, and advice to students as they collected data about their school for this project. Students worked in groups to collect and analyze data and findings from the audit. The first author in this paper has taught the Engineering Design course regularly and taught the ECE course to the 2014-2015 cohort.

*Additional ECE Supports*

Students participating in ECE receive tutoring support from Northeastern college students. This support is designed to ensure students perform well on mathematics high school coursework that is related to the Clean Energy course. The tutoring provides students with an opportunity to interact with college students.

A unique aspect of the ECE project offered to the 2014-2015 cohort of students was the opportunity for public presentations of the final project recommendations. In May 2015, five groups of students presented findings and recommendations for energy efficiency improvements to school administrators, parents, and a representative from the mayor's office at the end of the school year. Two of the five teams with the best analysis and presentation received a monetary prize. In addition to the usual quantitative methods of determining student learning (test/homework/projects) the project was also assessed by an outside evaluator.

## Methodology

Annually, the faculty member who has taught the Engineering Design course and independent evaluator have collected data from each cohort of students participating in the ECE program. The faculty and independent evaluator have employed quantitative and qualitative methods for data collection, analysis and reporting.

The independent evaluator has collected survey data from participating students. Surveys have been administered to students at the beginning of the Engineering Design course, in the middle of the course and at the conclusion of the course. The independent evaluator has also conducted student focus groups as well as observations of student presentations and analysis of student. In addition, a leadership team (comprised of faculty from Northeastern University, the EEED personnel, as well as John D. O'Bryant faculty responsible for teaching mathematics) has participated in focus groups to provide perspectives on the nature of the ECE and their perceptions of the course.

Faculty members who have taught the Engineering Design course have collected and analyzed student grades, which are based on homework and performance on class projects as well as tests.

The quantitative analytic methods that have been employed include descriptive statistical analyses to determine frequencies and averages. The qualitative methods were guided by Miles & Huberman's[1] framework of creating an initial coding schema, refining the codes, and exploring emerging themes and trends. Qualitative data are coded based on a schema that examined the relationship between actors (such as faculty and mentors), activities (such as the mentoring supports), outputs (such as number of students and hours the course was offered) and desired outcomes (such as interest in Clean Energy) and confidence to succeed in College.

## Results/Findings

The ECE recruited and provided an early college experience to a racially/ethnically and economically diverse group of high school students. After participating in the ECE program, the 2014-2015 cohort of students reported increased interest in Clean Energy careers, increased content knowledge, and an increased understanding of college coursework. Moreover, the 2014-2015 cohort of students reported increased grades compared with those of previous cohorts of ECE students.

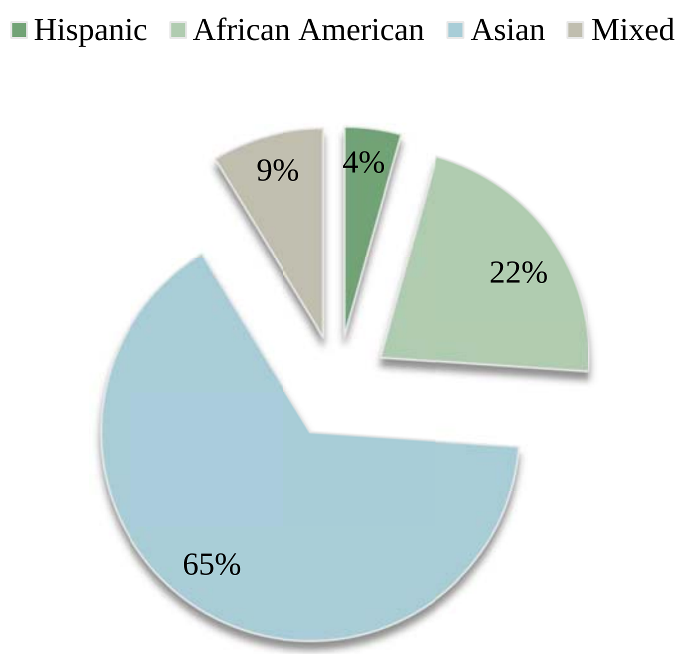
*Students*

Annually students have been selected for the ECE program based on grades, rigor of high school mathematics coursework, and an essay each wrote in response to the question on why they wanted to be a part of the program. The first selection criteria for the ECE program has been to select highly competitive seniors or juniors, and then to give preference to females and students of color.

For the 2014-2015 cohort, a total of 45 students from the John D. O'Bryant School of Mathematics & Science (referred to throughout this paper as the O'Bryant) applied to participate in the ECE for the 2014-2015 academic year. The O'Bryant is the only exam school in the Boston Public Schools that mirrors the overall student population of BPS, with total minority enrollment of 89%. Furthermore, 69% of the students are from economically disadvantaged backgrounds.

From the 2014-2015 applicant pool (which included more males than females), 35 students were selected to best match the demographics of the O'Bryant and with the additional aim of achieving an equivalent gender balance. From this cohort, after the first semester, there were 21 students who persisted in the ECE program. Of the students who persisted in ECE, 35% were female (which is higher than the College of Engineering's female enrollment of 25%). Moreover, the majority of the persisting students remained minority as shown in Figure 1.

**Figure 1. Race/Ethnicity of Persisting Students**

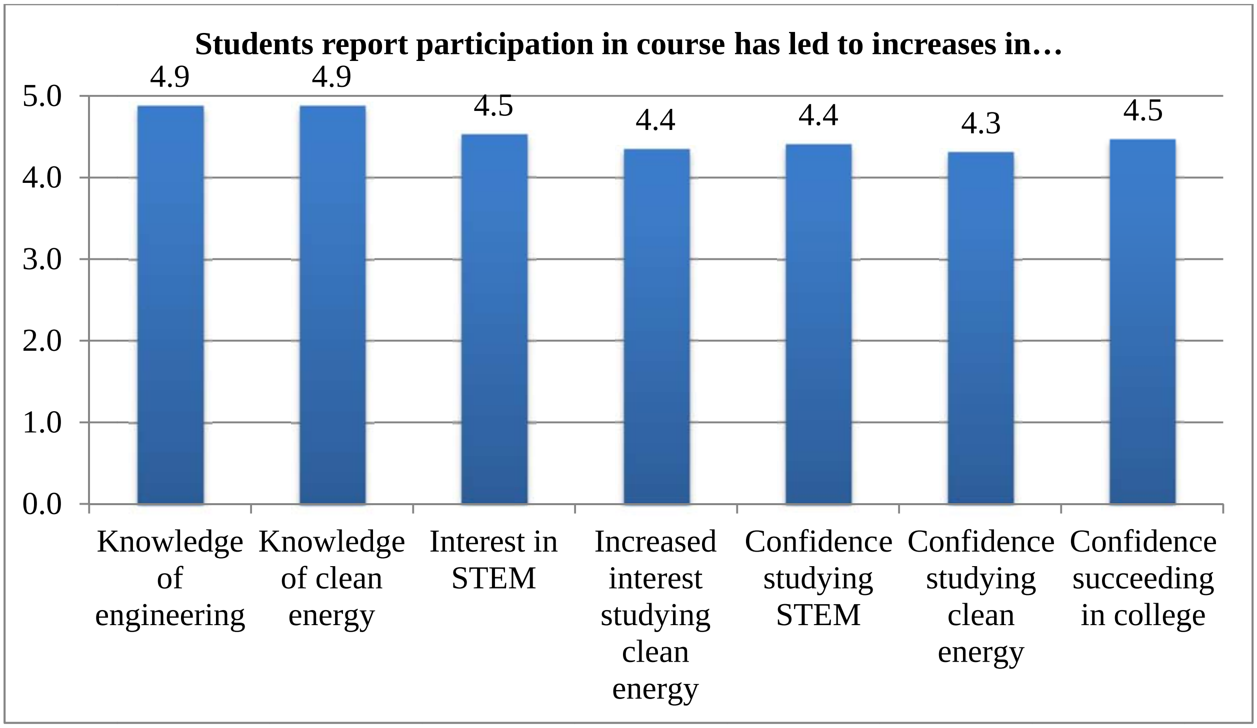



All students from the 2014-2015 cohort who completed the ECE were accepted into one of their top choice colleges or universities. No Scholastic Aptitude Test (SAT) data were collected from the students but based on an analysis of the colleges where ECE students were accepted it is likely that average SAT score were lower than the 2014-2015 cohort of Northeastern University Engineering students, which was 1430 (out of 1600).

*Survey and Interview Findings*

Analysis of survey data reveals that students involved in ECE have reported increased interest in Clean Energy careers, increased content knowledge, and an increased confidence regarding college success.

**Figure 2. Survey Data Findings**




As depicted in Figure 2, a total of 21 students who participated in the 2014-2015 cohort of students reported increased knowledge of engineering, and confidence in their ability to succeed in college-level engineering courses, interest and confidence in studying STEM, and interest and confidence in studying about clean energy . Interview data collected from students also corroborated the survey findings. For example, participating students stated:

> *"I planned to major in pharmacy before my participation in the course. However, when I get to know more information about the engineering field through this early college experience course, I was persuaded to the engineering field."*
>
> *"I believed that engaging details on clean energy were most effective in promoting students' interest in science, technology, engineering and math."*
>
> *"I am highly considering Green Engineering as my future career."*
>
> *"The thing that promoted our interest the most was learning about how much we could do to implement the idea of clean energy into our school and even the rest of our lives moving forward."*

Moreover, students reported interest in the design project, as they act as the designer and the client. Examples of student reports include:

> *"I now know a lot about how to use energy in the right way, to save energy around me. I even know how much difference it makes in having single pane windows and double pane windows."*
>
> *"I really enjoy the project aspect because it gives is the chance to make a difference in our own school."*
>
> *"I believe that the most effective was involving students in auditing their own school. This is a great experience because they are used to the environment, they go to school on a daily."*

*Course Data*

The Northeastern faculty member who taught the Engineering Design course administered exams to the high school students that had identical questions to those given to the college students to allow for comparison.

Analysis of student grade data shows improved average exam scores for the ECE students between the 2013-2014 cohort of students and the 2014-2015 cohort of students. Table 1 shows the average midterm and final grades of the ECE students compared to college students taking the same course with the same professor. Trends of note include a decrease in average score between midterm and final exams for all high school and college students that did not experience the real-life project. Conversely, the high school students involved in ECE scored higher on final exams than midterms, at a value almost equivalent to the college students. This is quite important, as the average SAT score for Northeastern students is quite high (as noted in the student section of the paper).

**Table 1. Comparison of Average Exam Scores for Same Professor**

| | High School Students | | | | College Students | | | |
|---|---|---|---|---|---|---|---|---|
| | 2013-2014 | | 2014-2015* | | 2013-2014 | | 2014-2015 | |
| # students | 23 | | 26 | | 57 | | 94 | |
| Exam | Midterm | Final | Midterm | Final | Midterm | Final | Midterm | Final |
| Average | 79.0 | 74.7 | 82.6 | 87.3 | 88.2 | 86.6 | 89.9 | 86.7 |
| * Real life project –energy audit -- instead of hypothetical project. | | | | | | | | |

*Professor's Reflections*

Anecdotally there were noticeable differences between the 2014-2015 students in the ECE and all other students (both high school students from previous years and college students.) With the students involved in the 2014-2015 ECE, students spent more time after class asking meaningful questions. Students sought answers to questions regarding knowledge on technology as well as questions regarding design ideas and processes. It was apparent that the students' identification with solving the problems with their school's energy inefficiencies was very personal to them and it was especially impressive that they were able to speak very professionally about the issues. For example, having experienced a teacher's frustration with a broken light sensor in a math class, one student spoke with the professor many times about both the energy and user issues involved with fixing such a problem, so that a proper solution could be designed. While the 2014-2015 ECE students were slightly disadvantaged with formal knowledge over the college students taking the course, the informal knowledge gained from attending their school (which was the subject of the project) gave them an institutional expertise and confidence which manifested in how they came to their final designs and how they presented them.

## Conclusion

The mixed-methods evaluation reports have shown that each cohort of students has achieved increases in content knowledge and interest in clean energy after participating in the ECE project. Data collected over the past three years reveals that ECE appears to be a promising model of engaging minority and economically disadvantaged students in an early college experience. Moreover, analysis of qualitative data reveals that students were very positive about the focus on a real-life engineering design project. As institutions of higher education consider methods of engaging typically under-represented youth in engineering, the project provides a useful model as to what can be achieved by students.

## References

1 Miles, Matthew and Huberman, A. Michael. Qualitative Data Analysis (2nd edition). Sage Publications, Thousand Oaks, CA, 1994.
2 Schilder, Diane, Annual Early College Experience Evaluation Report, EAS, Inc., Cambridge, MA, 2014

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# Designing a Scalable Mechanical Engineering Freshman Year Experience for Relevant and Engaging Hands-On Experiences

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## Abstract

This paper describes the design, implementation and results of a new Mechanical Engineering Freshman Year Experience course being offered at the University of Massachusetts Lowell. The new course integrates meaningful hands-on experiences using inexpensive desktop CNC machines, core concepts laboratories, Matlab programming and communications. The two-credit course comprises both a 1-hour per week lecture and a 2-hour per week laboratory experience. The course is scalable in nature, with 19-students per laboratory section. A preliminary motivation study indicates that the students in this new course have higher intrinsic motivation than engineering students in traditional lecture-dominant courses.

## Keywords

Freshman year experience, Mechanical, CNC

## 1.0 Introduction

Student retention in engineering programs is an area of increased national focus and need[1]. Because there is no defined content in introduction to engineering courses, First Year Experiences (FYE) in engineering are often unique to the institution and can vary drastically in both deployment[2-7], and desired outcomes[2-7]. One of the many challenges of any FYE program is the reconciliation of student enrollment, student engagement and faculty time, budget, and space resources. Higher student retention rates are positive for the students, institution as well as the national STEM needs; however, there appears to be no “one size fits all” Freshman Year Experience to guarantee student retention.

Freshman engineering experiences vary from one engineering program to the next. Several engineering colleges have adopted a *cornerstone-to-capstone* approach that engages students with a project intensive freshman year experience and then revisits this hands-on project philosophy through the curriculum to later culminate with a senior capstone design project[2,3]. The projects in the freshman year courses are often performed in small groups and introduce concepts and/or experiences from the major discipline. Many FYE courses of this type discuss the engineering design process[3] or a Human Centered Design Thinking process[3]. These programs, despite their pedagogy and design process of choice focus on hands-on experiences to highlight the discipline and engage students.

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To contrast this, several engineering programs expose engineering freshmen to a survey of the discipline through a FYE seminar or guest lectures[4-7]. Often these courses are characterized by a lecture or seminar series that highlights the fundamentals of the discipline and/or the opportunities that students might pursue after graduation. These courses may include some combination of computer programming, computer aided design, economics, ethics, and/or overview of disciplinary topics. These courses are typically offered in larger student cohorts and are more easily scaled than project based courses. In these courses, guest lecturers or seminar speakers are a common feature.

There are several freshman year experience courses that encourage students to pursue a personal interest in the field of engineering[8-9]. For example, several universities offer 'electives' as their freshman year experience allowing students to enroll in an area of interest. Students are exposed to engineering through a personal interest and thus are hopefully engaged in the engineering discipline. Depending on the university or college, the experience can be purely lecture based, purely lab based or some combination of the two.

Finally, there are several universities and colleges that provide a Freshman Year Experience preparation course as a sole engineering FYE course or in conjunction with an introduction to engineering course[3,5]. The goal of these FYE courses is to provide students with some campus orientation, strategic study skills, social integration and/or background to higher education.

Recently, the University of Massachusetts Lowell College of Engineering performed a reflective self-study, a peer evaluation, a student feedback/focus group and a student survey to determine how to redesign the introduction to engineering sequence[10]. This redesign was purposefully performed as a student centric reflection and evaluation. The freshman year experience redesign coincides with the appointment of a new Dean in the College of Engineering as well as with the deployment of several 'maker' initiatives, including: (1) an NSF grant to examine the impact of Hands-On Design and Manufacturing Experiences in Mechanical Engineering (*Hands-On MADE4ME: Hands On Machining, Analysis and Design Experience for Mechanical Engineers*) and (2) the design, development and soon to be deployed 8,500 sqft. makerspace. Additionally, the course redesign also comes at a time where the college of engineering is continuing to experience rapid student body growth. The objectives was to develop a First Year Experience that:

- Is easily scalable to larger (and smaller) student cohorts.
- Has small laboratory sections with <19 students.
- Takes advantage of the new makerspace environment
- Is cost effective, from both a financial and a faculty resource perspective.
- Must maintain or reduce the number of course credits (previously 4-credits).

In this paper we will present the pedagogical and course content changes that have been designed, implemented and preliminarily studied in the new *Introduction to Mechanical Engineering Course* at the University of Massachusetts Lowell. The goals of this freshman course are to increase the engineering relevance and representation of the engineering material being delivered while providing an engaging and representative hands-on learning experience for our freshmen students. The course integrates Hands-on CNC machining experiences, exploratory laboratories, Matlab programming and professional communications. The course has been offered three times and continues to evolve with each offering. In this paper we focus on the Fall 2014 deployment.

## 2.0 Course Design Philosophy

The committee tasked with examining and recommending a new first year program performed both a focus group comprising ~25 students from all levels of the engineering curriculum (including graduate students) as well as a survey that was deployed electronically using SurveyMonkey.com. The focus group examined alternative models for the freshman experience course and solicited creative course offerings from students who intimately knew and experienced the University of Massachusetts Lowell engineering curriculum. The electronic survey solicited more specific student responses to targeted questions. These targeted questions were compiled to address both the committee's perspectives and concerns regarding the existing first year experience as well as the general outcomes and observations from the focus group study. The overall outcomes from this human-centered study included[10]:

- The students felt strongly about delivering relevant hands-on experiences. According to the students hands-on activities are important for maintaining motivation and connection to the discipline during their first year experience.[10]
- The students' responses suggested a strong preference for skills-based instruction and core engineering content over 'introductory information' such as campus orientation. Skills-based instruction included Matlab (or similar programming language), communications skills and CAD. [10]
- The majority of students surveyed knew which major they wanted to pursue, and as such wanted more discipline specific orientation and design experiences than a general overview of the engineering disciplines offered (as was previously done in the first introduction to engineering course). [10]

These primary student feedback-defined objectives informed the design and deployment of the new discipline specific Introduction to Engineering courses at the University of Massachusetts Lowell. First, the general discipline independent *Introduction to Engineering I* course was removed from the curriculum, freeing up 2-credits in the Engineering degree. The *Introduction to Engineering I* course comprised an orientation to the campus, a broad overview of engineering disciplines and engineering related topics (e.g.: problem solving, ethics, economics, MS excel, etc.). Since this course coverage was inconsistent with the student feedback, the committee recommendation was to remove the course from the curriculum and free up the credits and reduce resources in the FYE course[10]. The second committee recommendation was to overhaul the discipline specific introduction to engineering course (*Intro. To Engineering II*) to address student defined needs, namely: increased skill-relevant material and discipline specific coverage, more and richer hands-on activities and a deeper exploration of the specific engineering discipline.

This course would provide a discipline specific introduction to engineering. The overlap in skills-based instruction between several departments allows students interested, but not committed to a particular discipline to take an introduction to engineering course in one department (eg: Mechanical Engineering) and apply the credit to another closely related department (eg. Plastics Engineering) should they decide to change their major. Alternatively, students entering the Engineering College undeclared or undecided are encouraged to take one introductory engineering course in the fall semester (preferred field of study) and a second introduction to engineering course in the spring semester (secondary course of study) to assist with determining a major without affecting their subsequent years of study. Most students entering undecided are usually deciding between two courses of study; however, those who are truly/completely undecided can likely take a choice of two disparate introduction to engineering courses, have detailed discussions regarding their course of study with an advisor and move forward with sophomore level engineering in a chosen field of study.

The sections that follow describe how the new FYE was designed and implemented for Introduction to Mechanical Engineering.

## 3.0 The ‘New’ Introduction to Mechanical Engineering

The new *Introduction to Mechanical Engineering* course is a 2-credit freshman year experience course comprising 1-hour of lecture and 2-hours of laboratory contact per week. In the Fall 2014 offering in mechanical engineering, a single lecture/meeting of ~160-165 students was held each week. There were also 9-assigned laboratory sections, each comprising 19 students or less. The lecture component used clickers to assess attendance and gain real-time feedback from students. Homework is deployed using the Blackboard course management system. The Fall 2014 teaching team was comprised a pair of professors, 3 half-TAs (one responsible for CNC laboratory activities, one responsible for Matlab related content and one responsible for laboratory supervision) and 2 undergraduate laboratory assistants (both responsible for assisting in laboratory experiments and performing grading).

The course lecture component comprised five core topic areas:

- **Mechanical Engineering Fundamentals:** A brief lecture describing the core areas of study in mechanical engineering led this section. Following this introduction to the discipline lecture, a brief examination of key mechanical engineering concepts including forces, statics, dynamics, stress, strain and mechanical design was covered. The goal of this topic-based coverage was to expose students to the mechanical engineering discipline and the basic concepts in the ME curriculum.
- **Engineering Analysis and Problem Solving:** Engineering analysis and problem solving were tied in with the presentation of core topics in mechanical engineering. For example, a structured ‘sketch’, ‘given’, ‘find’, ‘known relationships’, ‘define solution process’ problem solving strategy was introduced in the context of mechanical engineering topics.

The goal of this topic area was to introduce students to structured problem solving strategies – a core engineering skill.

- **Engineering Design Process:** Two lectures were devoted to the engineering design process. These lectures examined the engineering design process as well as the design thinking[11] or human centered design philosophy. The goal of this topic area was to introduce students to the design process from empathy and problem definition through to testing and redesign.

- **Matlab Computer Programming:** Several lectures were devoted to introducing/scaffolding/using Matlab to solve engineering relevant problems and presenting results in a graphical format. Matlab was selected due to the ease of transferring this competency to other engineering disciplines should a student decide to transfer to a different department. Additionally, Matlab is used in downstream courses.

- **Engineering Communication:** Finally, a couple of lectures were devoted to effective engineering communication. This included report writing, graphical communication (graphs and sketches) and presentations.

Despite the known drawbacks of lecturing, the lecture component of this course was included as a venue for announcements as well as content delivery. Lectures were designed to be as interactive as possible with student activities (e.g., Bob McKim's/Tim Brown's 30 circles creativity activity[11] and hands-on computer programming) to engage students. Future course offerings will explore more 'active' learning pedagogies during the lecture, including drawing insight and creativity from large populations to enhance and advance engineering design and knowledge.

The introduction to mechanical engineering laboratory experience has thus far been the component most affected by the course redesign. What was previously a computer communications, literacy and competency course (learning Matlab, MS Excel, MS PowerPoint and MS Word) was transformed into an intensive hands-on project and problem based design and learning laboratory. The laboratory activities comprise both design projects as well as semi-structured laboratory experiments. All of these activities are focused around hands-on desktop CNC prototyping tools (**Figure 1**, Shapeoko II[12] and Zentoolwoks CNC machines[13]), light-duty tensile/compression testing machines (MK-10, **Figure 3**) and fans/wind tunnels to form the core hands-on experiences. These activities all required the use of Matlab data processing and engineering communications/reporting in the form of short written reports and presentations.

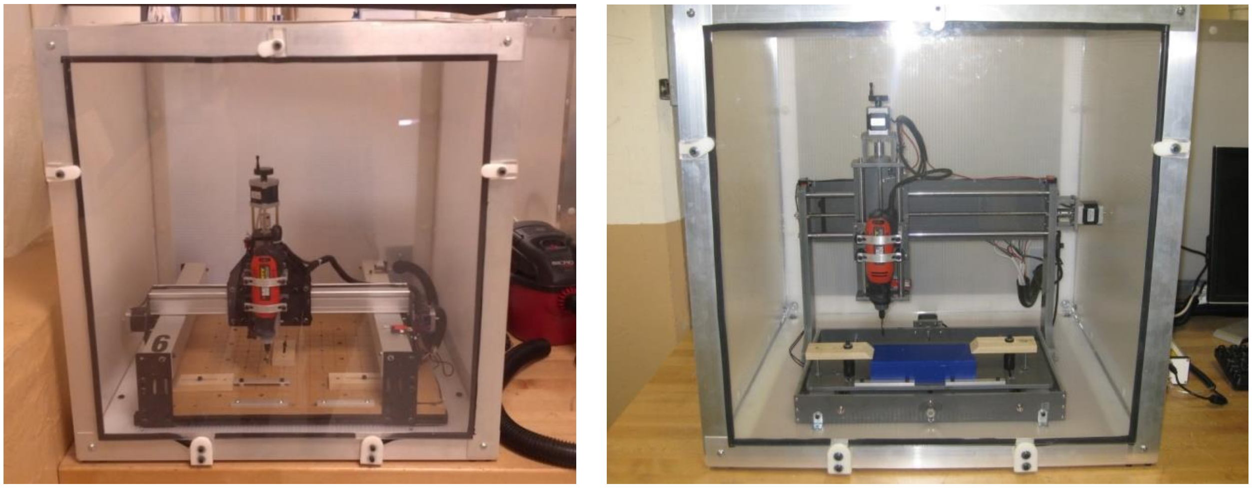


**Figure 1:** (a) A Shapeoko II with the University of Massachusetts Lowell modifications shown[12]. (b) A Zentoolworks 7" x 12" CNC machine[13].

The laboratory experience was divided into several educational blocks:

- **Team Logo Design Project:** This icebreaker activity is also the first student exposure to a complete design cycle (from inception to product testing). Students were told that the semester project would focus on wind power. The student groups were tasked to use an engineering ideation and design process to develop a logo for their wind power team. Teams were initially tasked to empathize with potential wind-power user groups and identify a core user-group need that the group's solution would target. This process informed potential products and 'mock company' values (problem identification). Students were then tasked to brainstorm logos individually and as a group for their team (ideation). Quantity over quality was stressed to increase students design confidence. The students were then asked to evaluate and provide peer feedback on logo designs by rotating through and critiquing each other's work (evaluation and cross pollination). After the group feedback, the students regrouped and finalized their designs (design down selection). The next step of the process was to develop a 2:1 scale drawing of the logo for digitization (design and specifications). The scale drawing exercise is assigned to introduce students to the concepts of scale drawing and visual communication. The students then digitize their logos using an in-house Matlab program. Following this, the students learn how to setup a CNC machine, install a block and wax and then mill the logo in wax. The wax logos are used to cast two-part platinum cure silicone (Smooth-On Moldstar) to create logo stamps. The culmination of the project is the logo unveil and testing (stamping ink onto paper to assess product performance). Students are required to write a 1-page memo reporting the *process* taken and the overall success of their logo project. The students are graded based on the *process* and not the *product*. This project is an accelerated design process that engages students and acts as an icebreaker. A student group logo design from this project is presented in **Figure 2**.


**Figure 2:** An example of a student logo stamp. (left) The milled machinable wax mold (center) The silicone stamp and (right) the resulting ink stamp.

- **Engineering Relevant Laboratories:** Since the University of Massachusetts Lowell Mechanical Engineering program has a comprehensive series of hands-on laboratories in the sophomore and junior years, the students are introduced to the engineering laboratory through three simple mini hands-on labs. These laboratories are performed in a single lab session and are relevant to mechanical engineering core concepts in thermal/fluids, materials science and strength of materials that can be applied to the assigned wind energy *semester project*:
    - **Paper Mache Material Science (Figure 3-left):** This lab exercise explores the properties of paper mache as a composite material comprising paper and flour base-glue. First students design and prepare dog-bone material coupon molds using the desktop CNC machines. Following this, students prepare samples at home using different formulations of paper mache. Some formulations are assigned (1 x similar formula for each group and 1 x different formula per group) while other material formulations are student defined within the constraint of being biodegradable. The students then use desktop MK-10 tensile testers to evaluate the tensile properties of paper mache – something that is not easily determined from an online search. In the lab students record the load and deflection, and then proceed to calculate the stress, strain and Young's modulus. Students use Matlab to process and graphically represent their data. The students deliver a four-page, group lab report. This laboratory exposes students to sample preparation, basic laboratory testing, data collection, data processing, material science and communication.
    - **Beam bending strength of materials (Figure 2-center):** This lab exercise explores the degradation of beam stiffness when kerfing is employed on a wooden beam. Kerfing is a process commonly used in woodworking to allow a piece of wood to become a bendable or a living hinge. By removing parallel slices of wood, the wood can be formed or bent. This is effectively a beam/plate bending exercise that alters the beam's second moment of area. Students were each assigned a single kerfing profile (i.e., a prescribed depth and spacing). Once the beams are fabricated, students perform a three-point bend test and share, collect and plot the data from each group in their lab section. The goal of this lab was to

understand and relate the kerfing parameters to the classical three-point beam bending equation. Students were also asked to graphically reproduce and functionally interpolate the beam bending profile using Matlab (with a YouTube video for guidance).

- **Finite wind aerodynamics (Figure 2-right)**: The final mini-lab examines the aerodynamics properties of finite wings using a teaching and learning wind tunnel. The wind tunnel (**Figure 2-right)** has a 12” diameter test section and produces a single wind speed (~45 mph). Students vary the wing’s angle of attack and record the lift and drag. The students convert the forces into non-dimensional coefficients and write a mini laboratory report (2 pages).

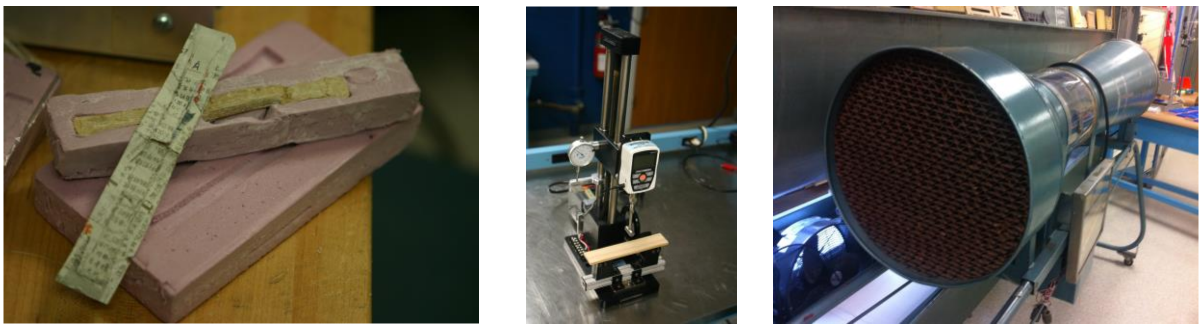


**Figure 3:** (left) An EPS ‘dog bone’ coupon mold was manufactured using the CNC machines to cast paper mache materials for tensile testing (center) A three-point bending test is used to test student beam samples (with kerfing) and (right) a low speed educational wind tunnel was used to relate angle of lift coefficient to angle of attack.

- **Semester Project:** Students are given the final 6 weeks of the semester to perform a cornerstone engineering design project (in the Fall of 2014 this project was a portable wind turbine design, in the spring of 2013 the project examined cellular phone add-ons). Students perform this final project as a group using a design thinking process and the knowledge gained during the laboratory activities to provide insight.

  The students were provided with a mechanical design for a low-cost adjustable wind turbine blade mold (**Figure 4**). This blade mold, once constructed could be used to develop wind turbine blades using paper/cardboard mache formulations (direct tie to earlier lab exercises). The blades themselves were designed using Matlab and evaluated for performance using a Matlab Blade Element Momentum Theory (BEMT[14]) code that was provided for the students. A separate mechanical and electrical test stand was used to test the turbine blade designs. The mechanical power output was evaluated by examining how long it took to lift a mass a certain height. The electrical power output was evaluated using a brushless RC motor to general three-phase current. These energy conversions and power output tests exposed students to core concepts of energy and power – often confused and poorly understood topics for mechanical engineering freshmen.

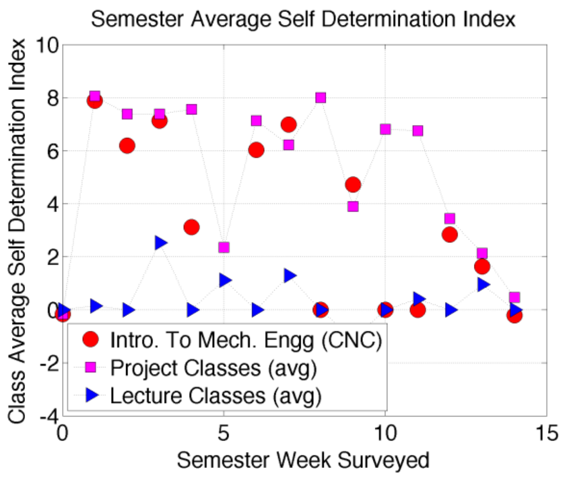
The students were given more freedom to self-direct their projects in this phase of the course. Each student group was assigned the task of developing a 6 to 8-page design portfolio comprising the ideation, design, manufacturing and test processes. The product design and manufacturing techniques were also required in this portfolio, though only a prototype system implementation (not a full system manufacture) was required. Finally, students presented their semester projects at an end of semester project expo.

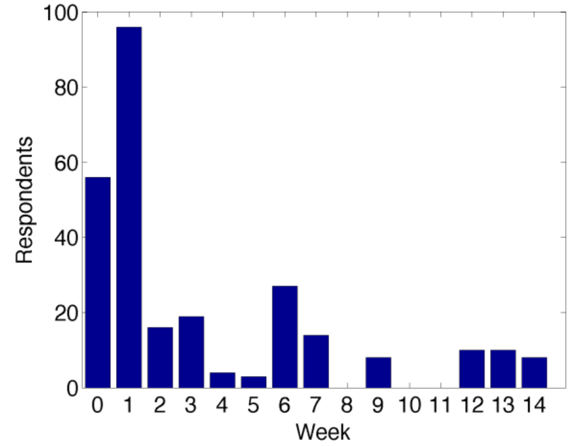
The modular course is easily deployed. Laboratory and design activities are easily deployed in this format. Additionally, the projects are easily scaled due to the low cost of the CNC machines that drive the manufacturing process.

**Figure 4: (left)** The adjustable blade mold system for fabricating repeatable wind turbine blades **(right)** Example of the diversity of paper mache wind turbine blades.

## 4.0 Preliminary Assessment of the New Introduction to Engineering Course

In addition to introducing curricular changes, we also performed a weekly student motivation self-assessment study to gage student interest and motivation. These results indicate the students enrolled in the course have high self-reported motivation as compared with the students in lecture-based courses (**Figure 5**). A 16-item SIMS survey[15] was used to assess self reported motivation. The surveys were deployed ~weekly in lab using paper surveys; however, the comparison classes deployed both paper and/or electronic surveys. Overall, the hands-on engineering courses exhibited higher self-reported intrinsic motivation, indicating that this course redesign is soliciting high levels of intrinsic (self determined) motivation. Unfortunately, survey response rates dwindled through the semester resulting in less reliable student motivation conclusions; however, the trend-based data is promising.




**(left)** The self-determination index for Introduction to Mechanical Engineering compared with project based, lecture based courses.

**(right)** The weekly number of *Introduction to Mechanical Engineering* SIMS survey respondents.

**Figure 5: (left)** Overall SIMS motivation over time data for three courses in this study, and **(right)** survey response rates for the Introduction to Engineering course.

From a faculty perspective, the course is easily scalable. Students are given opportunities to design and interact with advanced machining methods in an accessible manner. Students in general appear to have increased positive reactions to this learning-by-doing environment.

## 5.0 Lessons Learned

The new introduction to engineering course has resulted in a more focused, hands-on discovery of the mechanical engineering field. The following lessons have been learned through the implementation process:

- Developing useful and accessible software interfaces for students that enable facile use of CNC machines in the classroom at an introductory level is challenging. A simple Matlab GUI/CAD-CAM interface has been developed; however, many students expect a high level of software interaction, refinement and capability. As a result, teaching basic CAD and using DXF/STL converters is being considered for future course deployments.

- The course requires a significant writing and reporting workload, both on students, course staff/TA’s and faculty. In the first offering, complete lab reports were required; however, over time, the focus has been on ‘results’, ’observations’, ‘discussion’ and ‘graphical representation’ sections. The reason for this is twofold – first, the students can focus on the core aspects of engineering/scientific writing (presentation of results and discussion) and second, the focused effort reduces workload.

- Having competent and well-trained teaching assistants and teaching staff is a significant factor in the success of a hands-on intensive course. The teaching staff consists of graduate teaching assistants (in charge in laboratory) as well as undergraduate graders (who assist in lab and perform grading tasks). Luckily, our teaching staff has been well prepared and very competent, lending significant success.
- The complexity of most kit based desktop CNC machines is high and as a result, it can be challenging to deploy a CNC laboratory experience in this fashion. This said, the inexpensive CNC machines provide a less intimidating, more accessible experience for students. This ‘error friendly’ environment enables students to explore and try engineering without the worry of significant damage to a machine or to their confidence.
- Materials selection and manufacturing processes available for freshman engineering need to be carefully considered. Softer materials are more than adequate for most freshman engineering applications (ie. Plastics, wax, silicone, etc.). This said, standardizing materials for freshman usage requires some planning and preparation. Class size and challenges of scale drive cost of deployment; hence, material and part selection plays an important role in the course deployment cost.

Overall, from an instructional perspective, the course provides an overview of mechanical engineering and the mechanical engineering curriculum. The instructional team continues to iterate and improve based on end-of-year reviews and student weekly reflections.

## Conclusions

The freshman year experience in Mechanical Engineering at the University of Massachusetts Lowell has been redesigned to incorporate a higher level of hands-on engineering and design experiences. Desktop CNC machines have been integrated into the laboratory component providing students with making experiences and ownership of lab as well as projects. The intensive hands-on nature of the course appears to have solicited a higher intrinsic motivation from our students. This said, further survey results are required to fully assess this new course design.

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## References


1. LeBold, W.K., and S.K. Ward, "Engineering Retention: National and Institutional Perspectives," Proceedings, American Society for Engineering Education Annual Conference, 1988, Portland, OR.
2. http://engineering.dartmouth.edu/courses/13winter/engs021/schedule.html, last accessed 3/22/2015.
3. http://www.cit.cmu.edu/current_students/first_years/introductory_electives.html, last accessed 3/22/2015.
4. http://eeic.osu.edu/first-year/, last accessed 3/22/2015.
5. http://www.engr.ncsu.edu/academics/undergrad/firstyear/common, last accessed 3/22/2015.
6. http://engineering.vanderbilt.edu/ge/es140/, last accessed 3/22/2015.
7. http://www.eng.ufl.edu/students/career-resources/egn1002/, last accessed 3/22/2015.
8. http://engineering.tufts.edu/docs/IntroEngF12.pdf, last accessed 3/22/2015.
9. http://www.engineering.cornell.edu/resources/advising/orientation/upload/ENGRI-Offerings-2013-FINAL.pdf, last accessed 3/22/2015
10. J. Weitzen, D.J. Willis, E. Maase, S.P. Johnston, M. D. Rashid, *A Methodology for Restructuring Our first year Introduction To Engineering Sequence at University of Massachusetts Lowell*, Paper to be presented at the 122nd ASEE Annual Conference and Exposition, Seattle, WA, 2015.
11. http://www.ted.com/talks/tim_brown_on_creativity_and_play?language=en, last accessed 3/22/2015.
12. https://www.inventables.com, last accessed 3/22/2015.
13. http://zentoolworks.com, last accessed 3/22/2015.
14. J. F. Manwell, J. G. McGowan, A. L. Rogers, *Wind Energy Explained: Theory, Design and Application*, Wiley Publishing, 2 edition, New York, 2010.
15. F. Guay, R.J. Vallerand, and C. Blanchard, *On the Assessment of Situational Intrinsic and Extrinsic Motivation: The Situational Motivation Scale (SIMS)*, Motivation and Emotion, Vol. 24, No. 3, 2000.

# Capstone Project Selection and Evaluation Processes: More Fair for the Students and Easier for the ABET Evaluator

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## Abstract

While the specific focus of an ABET on site evaluation of student outcomes may vary year to year, design outcome assessment (ABET c) tends to always be under scrutiny. Searching for evidence of addressing realistic constraints, as well as meeting any discipline specific program requirements, can be a time consuming process for the evaluator, particularly if the capstone sequence spans two or more semesters. Capstone courses are frequently used for final assessments of many additional student outcomes, requiring a significant amount of time to also be spent identifying the evidence used in those outcome assessments. Following adoption of a philosophy that making the evaluation task easier for the program evaluator will lead to a better evaluation, a documentation process used to select and evaluate capstone senior design projects has been developed and employed. The documentation uses a project request for proposal form which includes identification of the realistic constraints that should apply to the design. Detailed rubrics used for the evaluation of oral and written reports include criteria that can be directly mapped to the assessment of other, non-design student outcomes. At this institution, the grading process involves faculty evaluations of both the written and oral reports by faculty members that were not the project advisors; further strengthening the assessment while simultaneously mitigating differences in expectations among different project advisors. While the direct effect on the ABET evaluation cannot be directly determined, the existence of the documentation was proven useful in focusing an ABET evaluator's attention to the assessment and evaluation evidence necessary to conduct the program evaluation in a timely manner. Specific aspects of the relevant documents, the design project evaluation process, and an ABET evaluation scenario will be presented.

## Keywords

ABET

Assessment

Senior Capstone Evaluation

## Introduction

A substantial part of any EAC-ABET self-study report and on site evaluation is devoted to Criterion 3 - Student Outcomes and the assessment of Criterion 3 as a part of Criterion 4 - Continuous Improvement. Although the Criterion 3 heading has changed over the years, from Program Outcomes to Student Outcomes, the outcome statements themselves have remained unchanged since the 2010-2011 criteria [1-3]. During the on-site review, program evaluators will tend to focus on areas that cannot be verified by the self-study report. While many of the student outcomes may require additional clarification during the on-site review, outcome c related to the design of a system, component or process, can only be verified by observation of evidence during the on-site review; typically a review of capstone design reports. Beyond the general student outcomes listed in Criterion 3, many individual program requirements specifically list design in a context that is appropriate to the individual discipline [1-3].

Due to the overarching nature of the capstone design course, it is not unusual for student outcomes other than outcome c to be assessed from student work generated during this culminating course [4-6]. While the assessment of multiple outcomes from a single course may be relatively efficient for the program faculty, the review of this student work by an ABET program evaluator during an intensive on-site review could easily result in missed or misinterpreted data, particularly when looking for evidence of the preferred realistic constraints, such as economic, social, political, manufacturability or sustainability [1-3]. A failure of the program evaluator to recognize the necessary evidence in a timely manner could lead to a less than satisfactory program evaluation. At the very least, some anxious moments between the program evaluator and the program leading faculty member will transpire.

One way to facilitate the review of student design work by an ABET evaluator is to use standardized documentation as a part of the normal project selection and course grade evaluation process that highlights the more difficult to identify design outcome identifiers. In addition, if other student outcomes are being assessed using the capstone design course deliverables as a data source, inclusion of documentation that indicates faculty evaluation of those student outcomes will make it easier for the ABET program evaluator to determine compliance with the criteria.

At Norwich University, the capstone senior project in the Mechanical Engineering program is conducted as a two semester sequence and assessment evidence for multiple ABET student outcomes is acquired from several deliverables that are evaluated as a part of the course grading process. This paper will present the project selection and evaluation tools and processes developed for the course. It will also outline our ABET continuous improvement process for student outcomes assessment and highlight how the tools and processes used as the normal course grade evaluation process provided a clear path between the student work and the outcome assessments.

## ABET Outcomes Assessment Process at Norwich

At Norwich University, the stated ABET a-k student outcomes have been slightly modified to reflect their application to the Mechanical Engineering program offered at Norwich. Due to the unique nature of Norwich as a Senior Military Academy and the initial home of the Reserve Officers Training Corps (ROTC), each of the engineering programs at Norwich has adopted a local outcome related to the development of leadership skills. Table 1 provides a comparison of the ABET student outcomes and the corresponding student outcomes for the Norwich Mechanical Engineering program [7].

The assessment process at Norwich evaluates each outcome in three different courses in the curriculum; an early introductory course, a mid-level course and a high level course using an outcome specific rubric. To reduce the workload associated with the assessment process, the twelve Norwich student outcomes were divided into three sets and each set is evaluated every three years. This allows all of the outcomes to be assessed fully assessed twice during the normal six-year accreditation cycle with each completed assessment being composed of two formative assessments and one summative assessment. The foundation of the Norwich process is that each outcome is evaluated by a faculty expert using an outcome specific rubric.

Table 1: Comparison of the ABET and Norwich Student Outcomes for Mechanical Engineering

| **ABET Outcome Statement (2014-2015 Accreditation Cycle)** | **Norwich Mechanical Engineering Program Outcome Statement** |
|---|---|
| (a) an ability to apply knowledge of mathematics, science, and engineering | 1. Apply scientific and fundamental engineering knowledge based upon a strong foundation in advanced math, chemistry, physics, and the engineering sciences. |
| (b) an ability to design and conduct experiments, as well as to analyze and interpret data | 2. Design and conduct hands-on experiments, use mechanical/electrical hardware, and 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 | 3. Design a component, system or process in the mechanical engineering field that meets performance, cost, time, safety, quality, materials, and manufacturing requirements. |
| (d) an ability to function on multidisciplinary teams | 4. Function as a member of a multidisciplinary team and be able to assume leadership roles on the team. |
| (e) an ability to identify, formulate, and solve engineering problems | 5. Identify, formulate, critically analyze, and solve engineering problems in energy conversion and transfer, materials and manufacturing, and mechanical systems design. |
| (f) an understanding of professional and ethical responsibility | 6. Recognize and achieve a high level of professional and ethical conduct in all aspects of engineering work. |
| (g) an ability to communicate effectively | 7. Formulate and deliver effective written and verbal communications of laboratory, analytical, and design project work to a variety of audiences. |
| (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context | 8. Understand and incorporate non-technical considerations into an engineering solution including safety, environmental, social, economic, and global issues. |
| (i) a recognition of the need for, and an ability to engage in life-long learning | 9. Recognize the need for mechanical engineers to engage in lifelong learning and begin the process by taking the FE exam. |
| (j) a knowledge of contemporary issues | 10. Be knowledgeable of contemporary issues in mechanical engineering and related fields. |
| (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. | 11. Utilize techniques, skills and modern engineering tools (including CAD/CAM) necessary for mechanical engineering practice. |
| | 12. Develop broad based technical skills and knowledge, strong work ethic, integrity, and leadership skills that will lead to successful careers in a wide variety of engineering and non-engineering positions in industrial, military, government, and academic settings. |

Although each course in the Mechanical Engineering curriculum contributes to at least one student outcome, measurements of individual outcomes to provide the formative and summative assessment data are collected in specifically designated courses where the contribution to the student outcome was particularly strong. For example, ABET Student Outcome c, related to a student's ability to design, has twelve different courses contributing to it, but it is only measured for assessment purposes in three courses: EG109 – Introduction to Engineering I, ME370 – Mechanical Systems Design, and ME468 – ME Design II; representing the two formative and one summative set of assessments.

While each course in the curriculum contributes to at least one student outcome, there are many courses that contribute to multiple student outcomes. In courses where the strong contributions were apparent, multiple outcomes were designated to be assessed. For example, ME468 – ME Design II contributes to eight of the Norwich student outcomes and is the designated measurement course for six outcomes listed summarily in Table 2. Due to the cyclic method of assessment described previously and the specific outcomes being assessed, each year at least one outcome is directly measured for a summative assessment in ME468, which is the final course of the ME capstone design sequence. Table 2 also indicates the year in the assessment cycle when the student outcome might normally be measured.

Table 2: A summary of the student outcomes assessed in ME468 – Senior Design II

| Summary of the Student Outcome | Typical measurement year in the three year cycle |
|---|---|
| Outcome 2 – Experimentation | 1 |
| Outcome 3 – Design | 2 |
| Outcome 4 – Teamwork | 1 |
| Outcome 7 – Communications | 1 |
| Outcome 8 – Non-technical Considerations | 2 |
| Outcome 12 – Leadership | 3 |

## Norwich University ME Senior Capstone Course: Project Selection and Grade Evaluation

The Mechanical Engineering Capstone course at Norwich University requires teams of 3 or 4 students to work on a project across the fall and spring semesters of their senior year. The students have already completed ME370 Mechanical Systems Design in the spring semester of their junior year. ME370 is a design methodology course focused on the new product development approach to design. Senior capstone projects are solicited from industrial sponsors and faculty members to ensure a sufficient number of projects are available to allow the students to have a choice of projects. In addition, students are encouraged at the end of ME370 to propose project topics of interest. In all cases, a project Request For Proposal (RFP) form is completed in order to help initially define and select the projects. The basic information solicited on the 2 page form is presented in Table 3.

Table 3: Norwich ME Department Senior Capstone Design Request For Proposal Information

| **Information Requested** | **Brief Explanation** |
|---|---|
| Project Title: | What the proposer would call the project |
| Contact Person: | Customer liaison or person proposing the project and their affiliation. |
| Background: | Brief reason behind the project being proposed. |
| Objective: | What is to be accomplished. |
| System Requirements: | Up to five, broadly stated requirements. |
| Deliverables: | Initial expectations of prototype, specialized documentation, or additional presentations. |
| Technical Requirements: | Specific skill areas that students will need to complete the project. |
| Customer Commitments: | What resources will the proposer commit to ensure project success |
| Additional Requirements: | What department resources (space, dedicated hardware/software etc…) required. |
| Anticipated Codes & Standards/ Realistic Constraints: | Known or anticipated applicable codes or standards.  Includes spaces to identify the ABET list of realistic constraints; i.e.<br><br>Economic (costs), Environmental, Social, Political, Ethical, Health & Safety, Manufacturability and Sustainability |

The RFP forms are used as a starting point for negotiating an academically appropriate capstone project, regardless of project sponsor. Project content, scope, and provisions for adequate financial and support resources are typical points for negotiation. It is also common for both student and industry proposed projects to require faculty guidance regarding identification of potential realistic constraints, and occasionally some applicable codes and standards that might readily apply to a specific project. For ABET purposes, this provides an indication that some of their realistic constraints are being considered and that further evidence of those considerations should appear in the project documentation. It is well understood that project requirements, including the applicable realistic constraints, may evolve as the project matures, but the final negotiated RFP establishes a suitable starting point for a project that will address the academic requirements for the course as well as meeting the sponsors design needs. The RFP also provides an indication of whether the projects involve mechanical systems, thermal/fluid systems, or a combination of both, which address Mechanical Engineering program specific portions of Criterion 5.

At the beginning of the fall semester, all of the approved projects are briefly described for senior students during the initial class meeting, and all of the RFP documents are posted for the consideration by the faculty and the students. Seniors “bid” on their top 3 project choices, indicating why they are interested in each particular project and what specific skills or motivations should qualify them to be assigned to the project teams. Teams consisting of three or four students are formed by the course coordinator. High priority is given to form teams to undertake externally sponsored and student proposed projects, provided there are a sufficient number of students who have indicated an interest in the project. Over the past 3 years, the only project to have a student team member that did not indicate a preference for that project was an instance where the student did not provide a list of preferences at all. In all other instances, student were assigned to a project that was either their first or second choice. Faculty mentor assignments were made based on allowable faculty workload, specific interests of the faculty or prior positive relationship with the sponsor.

The course grades for individual students are determined based upon the evaluation of several deliverables and observations. While most of an individual student’s grade is determined by the evaluation of their assigned faculty advisor, a significant portion of the grade is determined by multiple faculty. These include the evaluation of three oral presentations during each semester, and the evaluation of the final reports at the end of each semester. The oral presentations are evaluated by all course faculty using rubrics that are specific to each stage of the project development. Each rubric identifies multiple criteria that are to be evaluated and descriptors identifying characteristic attributes for “Exceeding Expectations”, “Meets Expectations”, Below Expectations”, and “Not Acceptable.” Point values are uniformly assigned for each category of performance based on a criterion’s value for a particular presentation. Other faculty and external sponsors who are able to attend the presentations are asked to provide feedback to the students using the same rubrics. All faculty rubrics are averaged to determine a grade for each presentation. The course coordinator collects all of the completed rubrics, determines the presentation averages, and maintains a record of the presentation grade along with electronic copies of the rubrics. The original rubrics are returned to the project advisors to provide feedback to the individual teams. In some instances, the presentation grade is assigned to a specific speaker, and in other instances the presentation grade is assigned to the team, depending on advisor preferences and their instructions to their teams. The rubrics also allow for minor grade adjustments when individual students distinguish themselves either positively or negatively relative to the rest of the team and these adjustments are figured into the grade assignment of the students, even if the presentation grade is considered a “team grade.” External evaluator feedback is provided to the teams when available, but is not used to determine the course grade.

End of semester final reports are also graded using detailed rubrics. Report relevant criteria are evaluated using descriptors identifying the same levels of performance relative to expectations as was used for the oral presentation rubrics. Each report is evaluated by two of the faculty advisors. Neither grader is an advisor for the team being graded. The purpose of this is two-fold: a) the written communication value of the report is better assessed by someone who is only vaguely familiar with the project and b) no student team has a specific advantage or disadvantage due strictly to their assigned faculty advisor. The team report grades are determined by an average of the two evaluator grades.

At the end of each semester, the course faculty meet to determine and assign the final semester grades for each individual. The portion of the grades that are evaluated strictly by the advisor, along with the presentation and report grade averages and the student peer evaluations are reviewed. Several deliverables evaluated by the faculty advisors, such as individual weekly progress reports and student design notebooks, contribute to individualizing the final grade averages. During the last semester, a portion of the final grade is determined by project success, which is determined by the course faculty and subjectively accounts for the satisfaction of the external sponsor if applicable.

## Project Grade Evaluation and ABET Assessment

It is a common technique to differentiate between the assignment of a course grade and the assessment of student outcomes. Embedded assessments, however, are also well established methods for using a portion of a student's coursework to determine the level of mastery of a particular student outcome. In the process previously described, the rubrics used to evaluate the oral and the written communications associated with the capstone projects are distinctly different than the rubrics used to assess the ABET student outcomes. Student course grades include many factors that are not directly related to specific student outcomes, but are considered important points of student learning. While the outcome assessment process is predicated on the evaluation by a faculty expert using an outcome specific rubric, it is felt that evaluation data provides a much stronger assessment of outcome attainment when it was based on the opinions of multiple experts. The rubrics used to evaluate the Norwich University ME capstone oral and written communications include embedded assessment evaluations and the grading process includes a review by multiple faculty experts.

As an example, ABET Student Outcome 2 regarding testing and experimentation is specifically addressed in the second semester final presentation rubric by a "Prototype Testing" criterion with descriptors and point values identified with Exceeding Expectations, Meets Expectations, Below Expectations and Not Acceptable. In addition, a specific chapter of the final written report is to be "Analysis and Testing" and the rubric provides detailed descriptors to assist in the identifying which of the four levels of achievement have been attained.

Other rubric criteria addressed the evaluation rubrics directly address conceptual and detailed design content in both oral and written communication formats and a final report section criterion devoted to "Manufacturing, Economic and Life Cycle Assessment." These grade related criteria provide evaluation data from multiple experts that directly relates to assessment of ABET Student Outcomes 3 and 8 regarding design and non-technical considerations. The overall presentation and report evaluations are used to assess ABET Student Outcome 7 related to communications. Separate outcome assessment rubrics for oral and written communications are used in Norwich's Student Outcomes Assessment process.

While the assessment of teamwork and leadership are not as apparent in the body of student work, they are primarily evaluated by the individual team advisors and discussed by the course faculty during the final grade determination meetings at the end of each semester. During the years when those Student Outcomes are assessed, it is relatively easy for each team advisor to assess each student teamwork and leadership mastery using the appropriate Student Outcomes rubric.

## How These Tools and Techniques Assist During an ABET Onsite Evaluation

As is typical of an ABET onsite evaluation, course notebooks containing representative student work are prepared for the evaluation team. The student work accumulated represents high, medium and low, but passing, grade levels of achievement. During the most recent ABET onsite evaluation, the program evaluator had been instructed to look specifically for evidence of the student work that was specifically used for the assessment of student outcomes. While the year of record for Norwich would have normally included only the local “Leadership” related outcome as being assessed in the Capstone Design course, the PEV was reviewing the general and program specific criteria related to design. It was certainly beneficial to direct the PEV’s attention to the RFP forms that were archived with the ME467 – ME Design I course materials to provide indications of anticipated codes, standards and realistic constraints, as well as the rubric evaluations of the written reports and the student reports themselves. It also was beneficial to direct attention to the specific sections of the final report rubrics that would be used to assess the other design related student outcomes in other cycle years.

Although not included in the course notebook, hardcopies of the oral presentation rubrics were quickly provided from the digital copies of the rubrics archived for grade determination meetings. Providing these additional documents, along with indicating specifically where to find the evidence of graded student work that would be used for the assessment of student outcomes made it easier for the PEV to locate and document his evaluation of program compliance with the ABET criteria.

## Conclusions:

This paper has described the process used by the Mechanical Engineering Program at Norwich University to select and administer their senior capstone design projects. A general description of the forms and rubrics used to define and evaluate certain key aspects of the projects was provided. A linkage between the key project criteria, their method of evaluation, and the ABET requirements for design was provided along with examples of of evaluation data being tied to outcome assessments. Finally, a scenario where the Request For Proposal forms and the presentation and report evaluation rubrics provided a means to expedite the onsite ABET evaluation was intimated.

There is a certain additional workload associated with the ABET accreditation continuous improvement process. Due to the summative nature of the culminating capstone design experience, it is frequently used for the assessment of multiple ABET Student Outcomes. Regardless of the specific schedule used to assess the student outcomes, design is often a program specific criterion to be addressed as a part of Criterion 5 – Curriculum. Consequently, ABET Program Evaluators are very frequently required to review faculty evaluated capstone design related student work and identify evidence linking the evaluated student work to the compliance requirements of ABET Criterion 3 – Student Outcomes and ABET Criterion 5 – Curriculum. By the strategic use of Request For Proposal forms to initially define and select the capstone design projects, and the use of rubrics, evaluated by multiple faculty experts, containing criteria that address design and other outcome topics, a direct connection between student work and assessment of student outcomes can be made. The embedded assessments are considered strong, direct assessments, and the evaluation by multiple faculty provides a strong evaluation process. Using these tools and this method for administering the senior capstone design course both facilitates the gathering of student outcome assessment data and the onsite evaluation by an ABET program evaluator. It seems reasonable that processes which make it easier for the evaluator to determine a program's compliance with the ABET criteria should lead to a more satisfactory evaluation.

## References


1 ABET "2010-2011 Criteria for Accrediting Engineering Programs", October 2009.

2 ABET "2014- 2015 Criteria for Accrediting Engineering Programs", October 2013.

3 ABET "2015-2016 Criteria for Accrediting Engineering Programs", November 2014.

4 Davis, D., Beyerlein, S., Thompson, P., Gentilli, K., McKenzie, L., "How Universal are Capstone Design Course Outcomes?", *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition,* Nashville, TN, June 2003.

5 McKenzie, L.J., Trevisan, M.S., Davis, D.C., and Beyerlein, S.W., "Capstone Design Courses and Assessment: A National Study," *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition,* Salt Lake City UT, June 2004.

6 Davis, K.C., "Assessment Opportunities in a Capstone Design Course," *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition,* Salt Lake City UT, June 2004.

7 Norwich University Mechanical Engineering ABET Team (Mountain, J., Friend, R., Wight, G., and Kelley, M.),"Self-Study Report for the Mechanical Engineering Program at Norwich University", pgs. 23-24, Norwich University, Northfield Vermont, 2014.


## Name of the paper's First Author

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# Preparing Civil Engineers for Construction Project Management

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## Abstract

Part of the Civil Engineering Program graduation requirements at the United States Coast Guard Academy includes the successful completion of a two-sequence construction project management study. This sequence consists of a *Construction Project Management* (CPM) course and a *Civil Engineering Design* (CED) Capstone course. The CPM course provides an introduction to the management practices of the construction industry, specifically focusing on how projects are planned and executed. Contemporary issues of the industry are also analyzed, including sustainable design. A unique requirement of the course is the completion of cross-disciplinary design project with two other courses offered during the same semester. The design aspect requires students to prepare detailed construction cost estimates that are properly indexed and identify applicable planning components, benefits of alternatives based on engineering economic principles, and determine essential project activities and completion times utilizing project-scheduling procedures. This approach has worked well because it provides the appropriate breadth and depth in project management and construction principles as well as design concepts for successful practice of civil engineering. Graduates from the program are well prepared to serve as civil engineers both in the Coast Guard and in the private sector.

***Keywords:*** *Assessment**,** Construction project management, cross-disciplinary, design project*

## Introduction

The United States Coast Guard Academy (USCGA), located in New London, Connecticut, is the smallest of the United States federal military academies. It offers bachelor degrees in eight majors-Civil Engineering, Electrical Engineering, Mechanical Engineering, Naval Architecture and Marine Engineering, Government, Management, Operations Research and Computer Analysis, and Marine and Environmental Science. Approximately 14% (130 students) of the Corps of Cadets major in civil engineering. The Civil Engineering curriculum includes a variety of required core courses in the humanities, science, engineering, mathematics, professional maritime studies, organizational behavior, management, leadership and law. The curriculum is broad and provides a solid background in the structures, environmental, geotechnical, and construction sub-fields of civil engineering. The Civil Engineering program places emphasis on helping students make connections between theoretical fundamental principles and real engineering practice[1]. As such, the courses are structured to help students develop the skills required for the real-life practice of civil engineering. This approach is in line with Chinowsky[2] who proposed that civil engineering programs broaden their curricula by providing more depth into management, ethics, entrepreneurship, business communications and financial management. Chinowsky argues that this will establish a professional knowledge base that will be capable of responding to both technical and managerial issues.

Information literacy is infused throughout the civil engineering curriculum, including the Construction Project Management course, to ensure that students not only develop the required communication skills but also identify the need for life-long learning[3]. In promoting information literacy, Wagner[4] described the importance of integrating effective writing instruction to improve the writing skills of undergraduate students majoring in Construction Management.

One of the educational objectives of the Civil Engineering Program at the USCGA is to produce graduates who are prepared to provide appropriate civil engineering expertise to the U.S. Coast Guard. Part of the Civil Engineering Program graduation requirements at the USCGA includes the successful completion of a two-sequence construction project management study. This sequence consists of a *Construction Project Management* (CPM) course and a *Civil Engineering Design* (CED) Capstone course. This approach has worked well because it provides the appropriate breadth and depth in project management and construction principles as well as design concepts for successful practice of civil engineering. Graduates from the Program are well prepared to manage construction projects within the Coast Guard. The authors discuss the various unique components of the CPM course, including the use of a cross-disciplinary projects, the development and selection of capstone projects as well as assessment of appropriate ABET outcomes.

## Overview of Construction Project Management Course

The Construction Project Management (CPM) course is a three credit hour, senior level course which introduces civil engineering cadets to management practices of the construction industry, specifically focusing on how projects are planned and executed. Topics include facility planning, design and contracting methods, construction drawings, specifications, scheduling, engineering economics, life-cycle cost estimating, facility risk analysis, engineering ethics, and overall project management. Contemporary issues of the industry are also analyzed, including sustainable design practices. The CPM course provides an introduction to the management, planning and execution of construction projects under both federal and private contracts. The knowledge gained in CPM is incorporated into the follow-up CED course and applied by students to successfully complete their capstone design projects. Students are introduced to the topics through lectures and activities that include case studies, guest speakers, construction site visits and semester-long team projects. In addition to providing significant assessment data to fulfilling ABET accreditation requirements, the course is viewed as vital in preparing future Coast Guard officers for successful careers as civil engineers in both Coast Guard and the private sector after graduation.

A unique course requirement is the application and coordination of several term projects with other courses. One of the design projects incorporates a cross-disciplinary design project coordinated with two other courses: *Geotechnical Engineering Design* and *Reinforced Concrete Design*. This combined project focuses on the complete design of a Coast Guard facility that includes a multi-story building, retaining wall, bulkhead, pavement and parking lot. Students complete the structural design of the building in the *Reinforced Concrete Design* course and develop foundation, bulkhead and retaining wall requirements in the *Geotechnical Engineering Design* course. The construction management aspects of the project, such as scheduling and cost estimating, are addressed in the CPM course.

The Capstone experience is also introduced in CPM as students are assigned their senior capstone project. Project teams are developed based on student and instructor input balancing student interest and ensuring that groups represent a range of talents and abilities. As part of the capstone preliminary exercise, students work in teams to prepare research papers, project posters and presentations that demonstrate their research and initial planning for designing their capstone projects. This combination of content delivery not only teaches the cadets basic skills of construction management and kicks off their capstone projects, but also introduces them to the Civil Engineering Officer specialty within the Coast Guard.

**Instructional Methods**

In order to fully expose students to construction project management and civil engineering within the Coast Guard and civilian sector, the CPM course is developed as a unique blend of in-class lessons, guest speakers, as well as construction site visits to government and private sector projects. Approximately 50% of the scheduled class meetings are dedicated to in-class lessons. These lessons are used to cover the relevant concepts and principles such as contract types and documents, bid packages, professional licensure, engineering ethics, scheduling, productivity, engineering economics, life cycle cost analysis, and construction safety. Each lesson is delivered with a mix of different instructional tools to accommodate the various student learning styles.

The use of guest speakers is a vital part of the instructional tools used because it provides exposure to wide ranging applications of construction practices and concepts. It also gives students opportunities to meet practicing professionals with vast experience in civil engineering. Approximately 15% to 20% of the semester is dedicated to guest speakers. Efforts are made to invite speakers from a variety of professions in the Coast Guard, other government agencies and private firms. These guest lectures typically provide not only a change of pace in the classroom, but also opportunities for students to experience construction from different points of view and positions. These experiences help students to develop a better understanding of engineering within their service as well as garner lessons learned from project execution depending on the discussions.

In addition to classroom instructions and guest speakers, several class periods (10 to 15%) are devoted to getting out of the classroom and experiencing construction projects in person. Typically, due to the size of our campus, there are several major projects going on at any time throughout the year. This enables students and instructors to easily walk across campus and gain access to a construction site. During these “walks”, students are able to compare construction drawings and specifications to the actual work being completed on site, ask questions of the project manager or superintendent and monitor progress over the course of the semester. In fall 2014 for example, the CPM class was able to visit a major renovation project taking place in the cadet barracks (student dormitory) as well as an exterior stairs and monument reconstruction. The stairs reconstruction project was visited in order for the students to compare construction drawings, specifically details and cross section drawings, with the hands on project in an effort to develop their skills in interpreting construction drawings. Students were also tasked to complete a productivity study of an operation taking place on campus. They observed either a construction site or coordinated team effort over an hour period recording data to complete a five minute rating. This data was then used to determine the productivity of the team of workers and explore ways to improve overall productivity and output. Other field trips to major construction sites off campus are also organized in collaboration with local construction firms or agencies. The objective of these trips is to reinforce material discussed in class through exposure to practical applications. They provide familiarization with equipment, operation, production management and problem solving in real life conditions. Instructors also use the opportunity to emphasize important concepts and applications during the visits. Examples of past guest lecture topics and site visits include:

- Project execution and construction of the “Q” bridge-Connecticut Department of Transportation
- Waterfront engineering- Collins Engineering
- Cadet Barracks Renovations- Facilities Design and Construction Center, USCG
- USCG Civil Engineering Program Management- USCG Office of Civil Engineering (CG-43)
- Hurricane Sandy Response and Immediate Repairs- USCG Civil Engineering Unit Providence, RI
- Waterfront Construction and Life Cycle Costs- Collins Engineers
- Coast Guard Academy Central Chill Water Plant- Facilities Design and Construction Center, USCG
- Connecticut Fast Track Transportation Project (CT FastTrack)-Connecticut DOT and Nobis Engineering.
- Maintenance vs Reconstruction and Construction Negotiations- USCG
- Engineering Ethics and Case Studies- Mr. Robert Gomez, VN Engineers
- Apprentice Engineering Assignments- USCG personnel

## Cross-disciplinary Project

Over the past three years, a cross-disciplinary project has been developed between *Construction Project Management*, *Geotechnical Engineering* and *Reinforced Concrete Design*. This combined project focuses on the complete design of a Coast Guard facility that includes a multi-story building, retaining wall, bulkhead and pavement. A schematic showing the cross-section of the multistory facility including the retaining wall is presented in Figure 1. Students complete the structural design of the building in the *Reinforced Concrete Design* course. Using the structural design results, the building foundation, bulkhead, retaining wall, as well as the pavement and parking lot designs are completed in the *Geotechnical Engineering Design* course. In CPM, the design aspect is to have students prepare detailed construction cost estimates that are properly indexed and identify applicable planning and/or bidding components, calculate costs and benefits of alternatives based on engineering economic principles, and determine essential project activities and completion times utilizing project-scheduling procedures. All of these are based on their design calculations from the other two courses. This project is progressive throughout the semester in the three courses and various submissions and deadlines are coordinated to ensure seamless transition. Some of the details of the CPM assignment are shown in Figure 2.

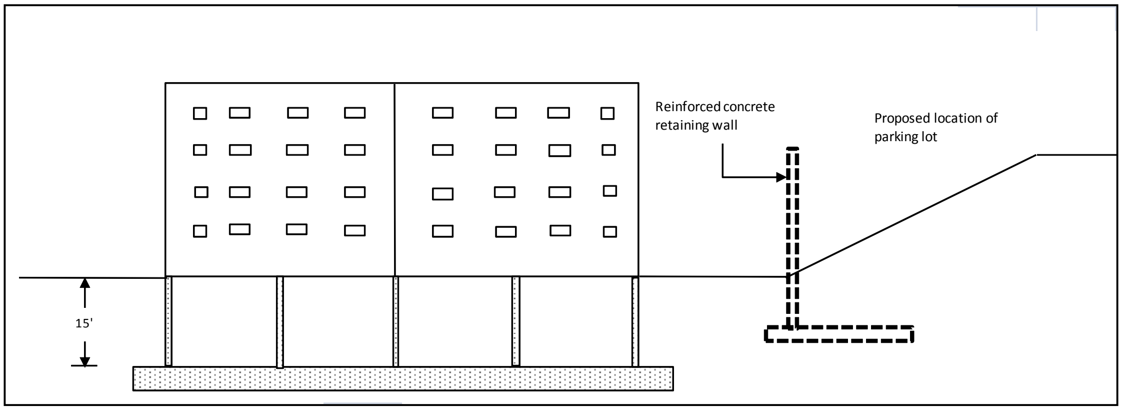


**Figure 1. Schematics of Cross-disciplinary Project showing side elevations**

**Subj: COST ESTIMATING SERVICES FOR COAST GUARD SECTOR LAMDA**

The following is a brief listing of the scope of work for the project:

-Excavation & preliminary site work
-Construction of reinforced concrete retaining wall
-Backfill & site grading
-Paved parking

*As supplemental guidance to the design contract, the Coast Guard would like to use sustainable and recycled materials to the greatest extent possible in this construction*

Additional information regarding the scope of work should be available through the Engineering Design Division of KES, which provided the detailed Geotechnical Engineering Design and Reinforced Concrete Design portions of the project.

**Deliverables:** Due **NLT 1600 – Tuesday, 18 November 2014**

Working in teams of 2, each team shall submit an Engineering Report containing the following:

**(1)** A detailed cost estimate using RS Means as a reference. The cost estimate should break down costs into Labor, Material, and Equipment components, and list at least 15 line items. You may use the list above as a starting point, and expand each into sub-activities using your previous work and engineering judgment. Up to 5 bonus points will be awarded for estimates containing more than 15 line items.

**(2)** Break down your estimate by CSI Division and line item number.

**(3)** Clearly indicate and articulate any assumptions made in the development of your cost estimate, including crew size & composition, project location, time factor, and mark-up rates.

**(4)** Assume that the previously submitted construction project schedule will be followed. Indicate the start date for the applicable portion of the overall Project, and inflate your estimate by an appropriate inflation factor.

**(5)** Adjust your cost estimate for a location factor assuming that the project will be constructed in the home town of one of your group members.

**(6)** Use the following mark-up values for your cost estimate:

a. Tax on Materials – use state sales tax rate for your selected location
b. Labor Burden = 55%
c. Contractor Overhead = 15%
d. Contractor Profit = 10%
e. Contingencies = 3%
f. Bonding = 2%
g. Inflation = 3% per year
h. Time Factor Adjustment – based on month and year this work scheduled to start

**(7)** List and describe any sustainable methods or materials included in your design and estimate.

**(8)** Compare your detailed cost estimate to the previously submitted conceptual estimate. Explain any differences in the two figures.

**(9)** Grades will be assigned using the following scale:

| | | |
|---|---|---|
| a. | Line Items are logical and complete | 30 points |
| b. | Calculations and markups are properly applied | 20 points |
| c. | Assumptions are logical and clearly articulated | 20 points |
| d. | Detailed estimate compared to initial estimate and difference between figures explained | 10 points |
| e. | Report professionalism | 20 points |
| | Total | 100 points |

**Figure 2. Sample of Cross-disciplinary Project Assignment in CPM**

This project allows students to better understand that in real-life, most projects will involve work from multiple disciplines that must all be coordinated to work together for successful completion of the projects. Initial assessment data indicates that this cross-disciplinary project is providing students with valuable problem-solving experience that better prepare them to tackle their capstone efforts in the spring semester.

## Preparation for Senior Capstone Project

The CPM course also includes preliminary work towards the senior capstone design projects that is completed in the follow-up *Civil Engineering Design* course. This preliminary work involves the selection of suitable capstone projects, formation of teams, initial site visit, research and presentations on areas of expertise that relate to their specific project. The capstone project selection process includes faculty consideration of constituent and student feedback, the ability to locate “real world” projects that can be successfully completed in the allotted single semester timeframe, and availability of funds. Project criteria such as funds for site visits, mandatory design component, project schedule, realistic stakeholder expectations, and the expertise of faculty advisors weigh heavily in the selection process. Capstone project topics are solicited from all Civil Engineering commands within the Coast Guard and the local communities to ensure the projects resemble future work that the students will experience as a civil engineer upon graduation. After a temporary list of projects is generated, the projects are grouped by discipline. Effort is made to have at least one project in each civil engineering subfield-structural engineering, geotechnical engineering, environmental engineering, and construction or multiple combinations of these depending on faculty interest and expertise. This list is then given to the students and feedback is solicited where they are able to rank order their top three project choices as well as provide input on potential team members, or project focuses that they would prefer. With this input and an understanding of each student’s strengths and weaknesses, teams are assigned by the CPM course coordinator.

After these teams are formed, students meet with their faculty advisors, discuss the problem statement for their specific project and determine research areas that must be explored prior to starting design work. Each student is required to select a topic related to the project, conduct thorough research and become the subject matter expert in that topic for the entire project. As subject matter experts, students are expected to be able to lead their team through these aspects of the project in the spring semester. Not only are students expected to fully understand their engineering research topic, they are also graded on their ability to find and choose reliable technical sources and demonstrate an appropriate level of competency in information literacy. Throughout the semester, the student teams meet with their faculty advisors and project sponsors to further develop the expectations and deliverables for the project. The research papers and planning work culminate in group presentations that share the problem statement, research areas and expected deliverables and plans for their capstone efforts.

## Assessment

The CPM course is used to assess the ABET outcomes and civil engineering specific criteria listed in Table 1.

## Table 1. ABET Outcomes and Performance Indicators

| Program Outcome | Performance Indicator (PI) | Assessment Tools |
|---|---|---|
| CE01 – Can apply knowledge in the areas of structural, construction, environmental, and geotechnical engineering | **CE01-4**: Apply fundamental principles needed to solve civil engineering problems in construction | Scheduling Project<br><br>Cost Estimation Project |
| CE04- Can explain basic concepts in management, business, public policy, and leadership; and can explain the importance of professional licensure | **CE04-1**: Describe the process and importance of professional licensure | Exam 1-Question 19 |
| | **CE04-2**: Explain basic concepts of management | Exam 1-Questions 13, 20<br>Exam 2-Questions 11, 12 |
| | **CE04-3**: Explain basic concepts of business | Exam 1-Questions 6<br>Exam 2-Questions 3 |
| | **CE04-4**: Explain basic concepts of public policy | Exam 1-Question 1<br>Exam 2-Question 10, 12 |
| ABET 3d (formerly ED04)- An ability to function on multidisciplinary teams | **3d-1**: Demonstrate commitment to team goals by actively supporting and sharing responsibilities with other team members | Mid-year Capstone Project Presentations |
| | **3d-2:** Plan and manage meetings, create strategies and execute plans of action | Meeting Minute Assignment |
| | **3d-3:** Explain and articulate the value of each team member's contribution to the group effort | Mid-year Capstone Project Presentations |
| ABET 3f (formerly ED06)-An understanding of professional and ethical responsibility | **3f-1:** Articulate the importance of professional code of ethics | Technical Journal Review 2 |
| | **3f-2:** Identify ethical dilemmas and propose ethical solution in accordance with professional code of ethics | Exam 1-Questions 9 & 10 |
| | **3f-3:** Investigate a given project and articulate ethical issues | Technical Journal Review 2 |
| ABET 3j (formerly ED10)-A knowledge of contemporary issues | **3j-1:** Identify several contemporary issues in civil engineering | Contemporary Industry Issue Presentation |
| | **3j-2:** Investigate, gather, and analyze information related to contemporary issues | Technical Journal Review 3 |

These outcomes are assessed through specific exam questions, the scheduling and cost estimating portions of their cross-disciplinary projects, their preliminary capstone project presentations, technical journal article reviews and a presentation on contemporary construction industry issues. These assessment tools are summarized in Table 2. One key assessment tool is the scheduling and cost estimation assignment that is part of the cross-disciplinary project. These assignments require students to prepare detailed construction cost estimates, identify applicable planning components, determine essential project activities, and establish completion timelines using project-scheduling procedures. An example of student performance on the cost estimation assignment for the graduating class of 2015 is shown in Figure 3.

## Table 2. Summary of Assessment Tools

| Assessment Tools | Description |
|---|---|
| Projects (general) | A total of 2 projects in which student are required to apply project management concepts and techniques to their own design work as completed in courses 1404 and 1411. Project performance was used to measure general understanding and application of course content. |
| Project 1: Construction Schedule Report | Given a proposed construction site, scope of work, and mandatory construction start date students are required to develop a construction schedule. Assignment deliverable is an engineering report which includes statement of given criteria, articulation of any assumptions made, the relationships between job activities, development of the network diagram and Gantt chart using MS Project, identifying the critical path, and activity start and finish dates. Students determine individual activity durations using crew size and productivity data from RS Means. |
| Project 2: Construction Cost Estimate Report | Given a proposed construction site, scope of work, and students' own work completed in Project 1, students are required to develop a construction cost estimate. Assignment deliverable is an engineering report which includes statement of given criteria, articulation of any assumptions made, and detailed cost estimate broken down by MasterFormat division and line item. Cost, crew, and productivity data is taken from RS Means. |
| Exam 1 | Problems require students to recall and explain basic course concepts including construction industry, project life cycle, contract documentation, legal aspects of construction contracts, engineering ethics, crew productivity, and project scheduling. |
| Exam 2 | Problems require students to recall and explain basic course concepts including engineering economics, project cash flow, life-cycle cost analysis, cost estimation, and construction safety and health programs. |
| Technical Journal Reviews | Students are required to research in technical journals, select three published articles, and summarize and analyze each. Research topics include (1) Contract Delivery Method case studies or theories (2) Construction Law case studies (3) Engineering Ethics case studies (4) Contemporary Industry Issues. |
| Contemporary Industry Issue Presentations | In teams of two, students research, analyze, and present issues contemporary to engineering or the construction industry. This assignment is follow on to individual effort technical journal review assignment specific to contemporary issues. |
| Research Paper | Senior Research and Design (Capstone) Projects are assigned to students teams. Students are individually assigned research topics by faculty advisors for the benefit of the overall project. With the given research topic, students develop a thesis statement, conduct research using a variety of sources, and write a paper developing their thesis in support of the team Capstone Project. |
| Preliminary Capstone Presentation | Senior Research and Design (Capstone) Projects are assigned to students teams. Students are individually assigned research topics by faculty advisors for the benefit of the overall project. After individual research is complete, teams present their research, preliminary design ideas, and their plan ahead. Achievement is assessed through performance during oral presentations. |
| Homework | Several homework reinforcing concepts and techniques discussed in class are completed throughout the semester. Assignments covered the following topics: (1) Project Scheduling, (2) Crew Productivity, and (3) Engineering Economics. |

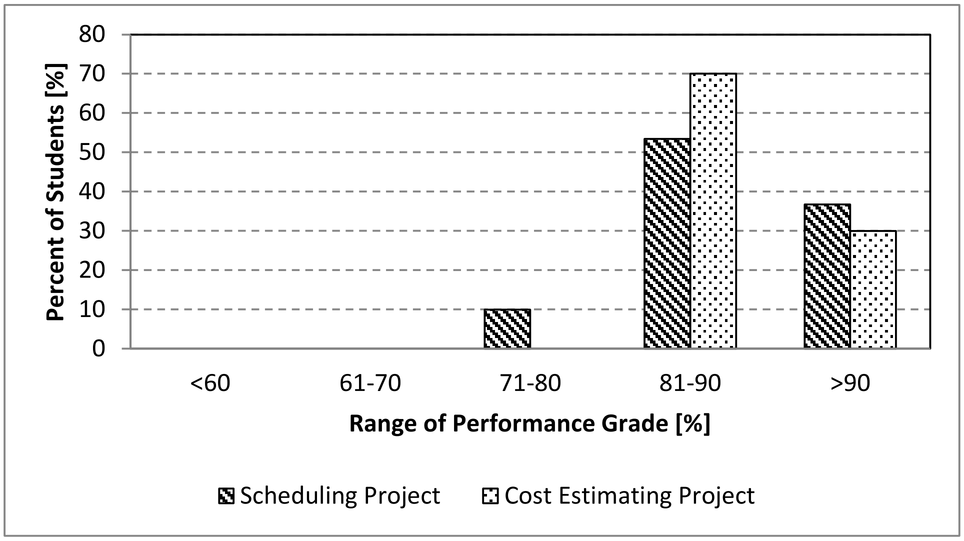


**Figure 3. Student Performance on Cost Estimating Project-Class of 2015**

Civil engineers serve in the United States Coast Guard as officers in a variety of career fields including, civil engineering specific assignments, engineering or deck officers onboard Coast Guard Cutters, basic flight training, or serving in response and prevention roles across the country. In their second or third tours (each tour is a 2-3 year job placement), many civil engineering graduates typically work within the Coast Guard Civil Engineering program. They serve as design engineers, facility mangers and construction project managers. In each of these roles, civil engineering graduates will be actively managing personnel, budgets and resources in order to successfully complete their assignments. The project management skills, as well as the Coast Guard acquisition exposure, offered in the CPM course prepare students for a multitude of career specialties within the Coast Guard. These skills can be applied to any career path civil engineering students will encounter upon graduation.

Based on post-graduation feedback, most alumni agree that the knowledge and skills acquired in the CPM course, specifically scheduling, cost estimating, productivity and economics were very useful in the successful performance of their duties. The contracting skills, planning and scheduling experience and knowledge of working on multi-disciplinary projects gained during the CPM course and from the civil engineering curriculum in general, greatly enhance their ability to succeed in these roles.

## Conclusions

The senior-level Construction Project Management course offered as prequel to the senior Design Capstone course at USCGA is discussed. This course introduces civil engineering students to current management practices of the construction industry, specifically focusing on how projects are planned and executed. The instructional methods used include a combination of in-class lectures, guest speakers, site visits, hand-on project based assignments, and a cross-disciplinary project. Guest speakers include a variety of civilian and military professionals from both the public and private sectors. The course provides exposure to contract methods, funding sources and limitations and typical project lifecycles from inception and funding, through design and execution, to completion. Discussion of several real-life projects, practical construction issues and cross-disciplinary project assignments give students a well balance global perspective of construction project management.

## References

1. Jackson, H, Tarhini, K, and Zelmanowitz, S., "Infusing Industry, Community and the Coast Guard into the Civil Engineering Program at the United States Coast Guard Academy," Proceedings of the 39th Frontiers in Education Conference, San Antonio, TX, 2009.
2. Chinowsky, P., "Integrating Management Breadth in Civil Engineering Education," Journal of Professional Issues in Engineering Education and Practice, Vol. 128, No. 3, 2002, ASCE.
3. Jackson, H., Rumsey, N., Daragan, P., and Zelmanowitz, S., "Work in Progress-Assessing Information Literacy in Civil Engineering," Proceedings of the 41st Frontiers in Education Conference, Rapid City, SD, 2011
4. Wagner, H., Hilger, P., and Flash, P., "Improving Writing Skills of Construction Management Undergraduates: Developing Tools for Empirical Analysis of Writing to Create Writing-Enriched Construction Management Curriculum," International Journal of Construction Education and Research, 10:111-125, 2014.

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# Collaborative Instruction and Team Based Project Learning - An Effective Strategy to Conduct Technology Education

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*The City University of New York*

## Abstract

Collaborative instruction is a teaching model that involves multiple instructors for a common set of educational goals, which can integrate the strengths and shared interests of faculty members with different expertise and research focuses. Just in time teaching for the project provides information for instructors to better understand how students learn in classroom. In this paper we present the practices and effectiveness of the collaborative instruction and just in time teaching pedagogy that we apply in the context of engineering technology education. We show how collaborative efforts have been made by multiple faculty members to immediately teach students useful skills and guide them in the understanding of engineering design principles in the area of embedded systems. With the combination of these methods, students with minimal math or programming backgrounds were able to independently initiate, design and develop technically challenging projects for a nationwide competition. One of the team projects "Elderly Independence" won the third place award in the USA 2014 Digilent Design Competition. This embedded digital system was designed and implemented by using the VHDL hardware programming language and programmable FPGAs. Our classroom experience indicated that collaborative instruction combined with just in time teaching of the basics for contest oriented projects stimulated students' interest in learning engineering design principles. Students demonstrated significantly faster development of engineering skills compared to those who followed the more traditional instructional approach.

## Keywords

Collaborative Pedagogy, Team Learning, Just-In-Time Teaching, Contest Oriented Project

## Introduction

Many instructional strategies have been advocated by the American Society for Engineering Education (ASEE)[1]: learning in small groups, active learning, cooperative learning, project-based learning, contest oriented project approach, team/collaborative teaching, etc [2,4,5,6,7,8]. For undergraduate engineering technology programs accredited by ETAC/ABET[3], graduates must demonstrate abilities satisfying ABET criteria. When faculty design and teach courses, we need to incorporate ABET criteria by applying effective teaching strategies. The Computer Engineering Technology Baccalaureate (CEB) program at the New York City College of Technology (NYCCT) of the City University of New York (CUNY) follows 2+2 model (AAS degree + BTech degree). This technology degree program has an open-access mission. Students enter with different academic backgrounds, with math levels ranging from Fundamentals of

Mathematics, College Algebra and Trigonometry, to Precalculus, and Calculus. What are some effective approaches to motivate, coach, and deliver instructions to this diverse student body? We have tried different classroom approaches such as active learning, team learning, problem based learning, and project based learning. We have conducted different teaching strategies in class including lecture-centered teaching and student-centered teaching. Recently we adopted an innovative contest-oriented project and collaborative pedagogy model in one class. Last year, the lower junior, upper junior and senior students who enrolled in the special project in technology class (CET 4982) showed a strong interest in participating in the USA Region Digilent Design Contest 2014. Participant teams in this contest were required to use the hardware and software platform provided by industry to design and develop a real-life product in about three and half months. Participants had to complete all of the following tasks: initial proposal, electronic components purchase, design and implementation, project screening, a website for publishing progress reports, a project demonstration, final team presentation, final technical report, and on-site demonstration of this FPGA or microcontroller based project. The students proposed two projects for the contest, titled as "Elderly Independence" and "Monitoring Makes Easy: Quadrocopter". According to the contest rules, students were required to use FPGAs or MCU to implement their design, which is really challenging to the students who did not have enough skills and knowledge on FPGAs and MCU. Moreover, to complete a functioning product, many techniques were needed, such as VHDL in embedded systems, feedback control, and signal processing. However, the students from this class had only basic knowledge of MCU and C/C++ programming, but not hardware programming language VHDL in embedded systems, FPGAs, feedback control and signal processing. To well prepare the students with knowledge across different courses in such a short period of time, four professors with different expertise in the Dept. of Computer Engineering Technology at NYCCT joined together and utilized the approach of collaborative instruction combined with just in time teaching for this particular course.

## Student Centered Teaching and Faculty Collaborative Efforts

Collaborative instruction integrates the strengths of multiple viewpoints and shared interests of faculty members with different expertise and research focus. For the two proposed projects , due to students' technical needs, we conducted different practices. By implementing collaborative and just in time teaching strategies, four faculty members collaborated to define common education goals, plan a timeline, develop class materials and deliver instructions to this particular class. After first few meetings with the students, faculty identified necessary knowledge and skills needed by each team of students for their contest projects. To fill the gap, we selected a set of technical contents from four courses at different levels along with other related technical topics that are not covered by any existing course in our curriculum. Specifically, technical contents that were selected from the four courses were digital system design using VHDL programming and programmable FPGAs, feedback control system and controller design simulated by MATLAB computing language, sensor interfacing, and computer controlled system design with Arduino programming language. The topics that we introduced for the teams but not covered in our existing curriculum were ECG sensor and PCB design.

We all have aging family members that are too independent and do not accept help. The motivation for the first proposed project "Elderly Independence" is to aid the aging population. The prototype was aimed to have the following features: i) monitor heart rate and provide assistance within a short response time; ii) detect odorless gas and smoke and turn off boilers and gas; iii) monitor a senior citizen with IR emitters and transceivers while he/she is in the shower in case of slipping and falling; iv) relay vital information to healthcare providers in case of emergency; v) implement the project on the Nexys 4 FPGA board using VHDL programming with external components, and vi) use Xilinx ISE WebPACK Design Software as the solution for FPGA programmable design. The system diagram of the project "Elderly Independence" is shown in Fig. 1.

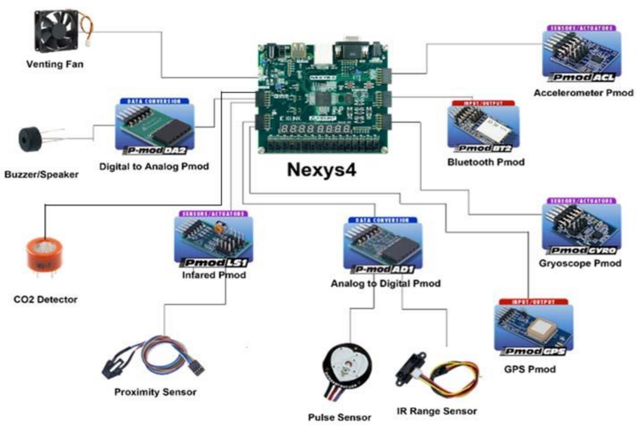



**Fig. 1 Elderly Independence**

To help students study and understand and be able to design a embedded digital system using VDHL hardware description language, one professor implemented just in time teaching in the classroom and adjusted the lesson flow. She developed accelerated tutorial lessons with exercise examples to introduce the topics of VHDL in digital logic design, VHDL code for decoder and encoder, VHDL in counter and frequency divider design. Furthermore, VHDL modules and port maps were integrated with Xilinx ISE WebPACK Design Software suit as shown in Fig. 2. However the students had tremendous difficulties in understanding the VHDL code for peripheral SPI and I2C data bus provided by industrial sponsor, and could not adapt and modify VHDL data bus modules into their project. To address this difficulty, one of the four faculty members developed and presented the I2C data bus peripheral implementation within Arduino programming enviorment (Fig. 3). He illustrated programming libraries through an example of Wii Nunchuk Controller [9] to explain I2C data bus protocol theory and its application. Although Wii Nunchuk Controller itself is not a part of our contest project, it is a good example that can be easily comprehended by the students. The technical principles learned from Nunchuk Controller example significantly enhanced students understanding of I2C bus VHDL module. Through collaborative instruction, the faculty members supplement each other's perspectives and lecture materials. Just in time teaching facilitated the learning of contents materials. The goals of teaching SPI and I2C protocols are accomplished best by faculty mutual support.

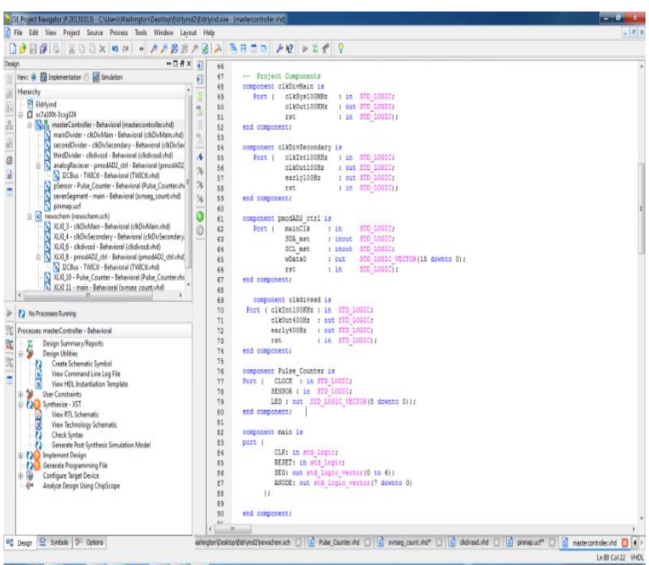


**Fig. 2 Digital Components Integration with VHDL**

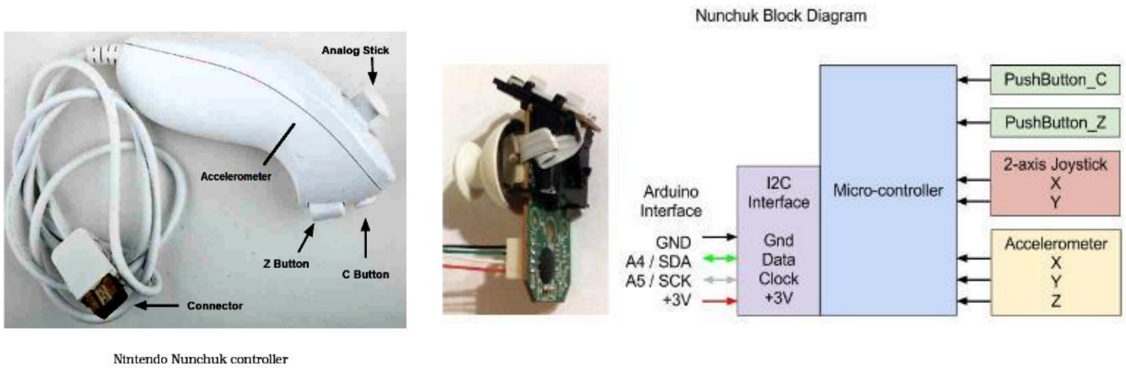
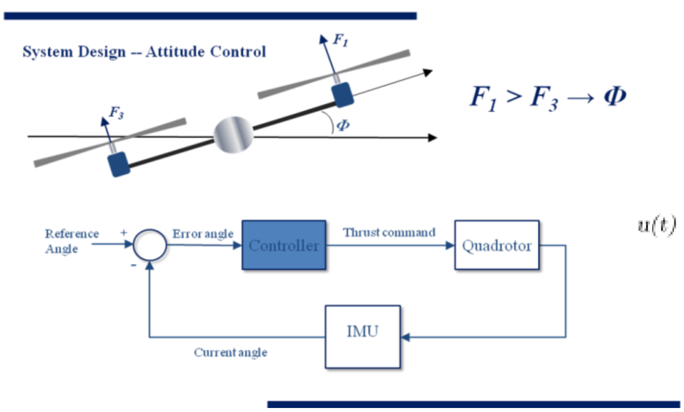



**Fig. 3 I2C Data Bus in Microcontroller Application**

Another example shown in Fig.4 is the prototype of "Monitoring Made Easy". The second student team constructed an unmanned quad-coptor outfitted with monitoring devices. The quad-coptor can locate and record the status of an object (human or animal). The data collected by the quad-coptor can be analyzed in a central location. The project consisted of the following tasks: i) build a quad-copter; ii) use ChipKit Max32 microcontroller development platform; iii) develop a software PID controller; iv) build a mobile monitoring device that would monitor the location of human beings or animals with GPS; v) interface with triple axis accelerometer and gyroscope sensors; and vi) transmit data to a central command center over distance. Students had good background knowledge of chipKit programming and understood the interfacing techniques well, but they lacked a background in feedback control systems, resulting in difficulties in PID controller design (Fig. 5).

**Fig. 4 Monitoring Made Easy**



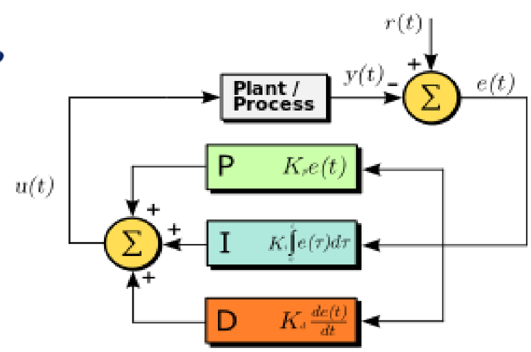




**Fig. 5 Control System Design -Attitude Control** **Fig. 6 PID Controller**

With such an ambitious plan, in three and half months, one of our faculty members developed a special lecture on the PID controller for the entire class. With MATLAB simulation and analysis of a Proportional gain (Kp), an Integral gain (Ki), a Derivative gain (Kd), and combinations of the three PID control parameters (Fig. 6), students were able to apply this knowledge to their project and programming the ChipKit microcontroller with supported programming library of feedback function and PID controller. Four wings of quad-rotor were controlled by a PID controller to minimize the error feedback to system. Finally, students were able to adjust the process by tuning the present error $P$ and the accumulation of past errors $I$ in the PID controller according to the process control outputs.

## Outcome of Collaborative Instruction and Contest Oriented Project Based Learning

With collaborative effort, professors gained insight and knowledge about another area of expertise as well as the effectiveness of collaborative learning. Student teams gained knowledge of the subject area through lectures, research, hands-on work, peer review, team work, oral and written communication. The contest oriented projects stimulate students' interest in learning engineering design principles. Collaborative pedagogy produced greater significant gains in student learning than those associated with the traditional instructional approach. Just-in-time teaching in the project created a need to know atmosphere, and helped instructors to better understand students learning in a particular discipline.


**Fig. 7 Student Team Members in Presentation**

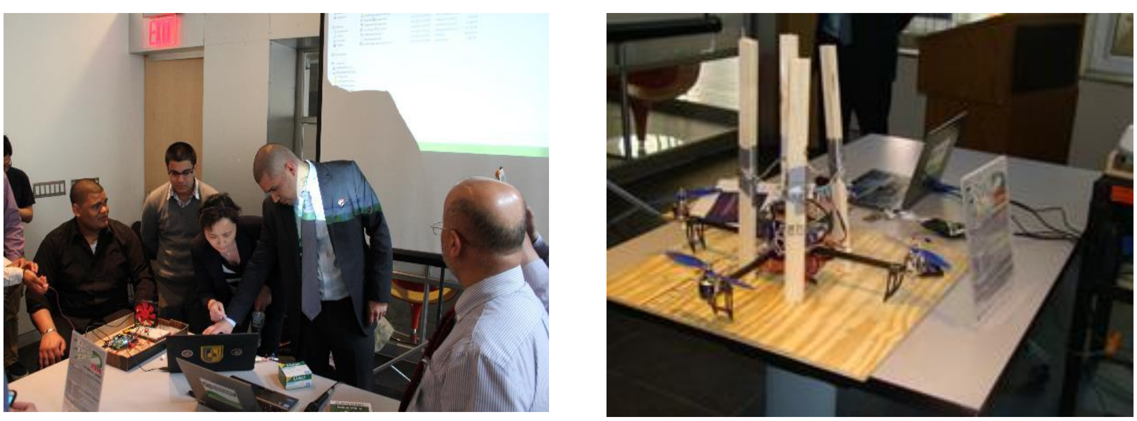


**Fig. 8 Project Demonstration in Contest**

Implementing the collaborative learning approach, students with different backgrounds were able to gain first-hand in-depth knowledge and practical experience about engineering project design and development. The two student teams then passed the contest screening and were able to participate in the USA 2014 Digilent Design Competition, as shown in Fig. 7 and Fig. 8. One of the teams proposed and designed the project “Elderly Independence” using the VHDL hardware programming language and FPGAs. The project won third place in the design competition. The panel of judges, which consisted of industry and academic representatives, evaluated the projects on conceptual innovation and technical implementation.

## Conclusion

This paper presented a contest oriented project with collaborative pedagogy and discussed the small classroom and student-centered teaching strategies. Classroom experience indicated that collaborative methods produce more significant gains in student learning than those associated with the traditional instructional approach. The just in time teaching and contest project approaches enhanced students’ engagement in the course. The outcome of the course has generated a conference poster and a publication. Students had the opportunity to learn to function effectively as a member or leader on a technical team. With industry's involvement and proper faculty guidance, our undergraduate students in the NYCCT CEB technology degree program were able to identify, analyze and design systems and components for broadly defined engineering technology problems.

## Acknowledgement

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## References

1 L. H. Jamieson and J. R. Lohmann, “Innovation with impact: Creating a culture for scholarly and systematic innovation in engineering education,” Amer. Soc. Eng., Washington, DC, USA, 2012.

2 J.E. Froyd, M. Borrego, S. Cutler, C. Henderson, and M. J. Prince, “Estimates of Use of Research-Based Instructional Strategies in Core Electrical or Computer Engineering Courses,” IEEE Transactions on Education, Volume: 56 , Issue: 4, 2013 , Page(s): 393 - 399

3 http://www.abet.org/

4 A. Steinkogler, P. Leibl, A. Seemuller, “Education for Collaboration,” 2012 the 18th International Conference on Engineering, Technology and Innovation (ICE), June 2012, Page(s): 1 - 9

5 S. Shandilya, K. Arya, K. Lala, P. Manavar, S. Patii, and S. Jain, “Learning by competing and competing by learning: Experience from the e-Yantra Robotics Competition,” 2014 IEEE Frontiers in Education Conference (FIE), Oct. 2014, Page(s): 1 - 8

6 D.J. Neebel, C. Merkel, A. Wong, “Engaging a variety of students in digital design with competition,” IEEE Frontiers in Education Conference, 2013, Page(s): 1091 - 1095

7 T. Hayama, et, al, “Analysis of Team Characteristics of Project-Based Learning Based on Performance Factors of Collaborative Learning,” 2014 IIAI 3rd International Conference on Advanced Applied Informatics (IIAIAAI), Aug. 2014, Page(s): 275 - 279

8 G. M. Novak, A. Gavrin, and C. Wolfgang, “Just-in-Time Teaching: Blending Active Learning with Web Technology,” Prentice Hall, 1999, ISBN:0130850349

9 Wii Nunchuck, https://github.com/timtro/wiinunchuck-h

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Sigrid Berka

University of Rhode Island

# Complementing on-campus engineering research experiences with tailored international research projects in partner universities and internships in industry abroad

## Abstract

The paper describes a tailored approach introducing International Engineering Program (IEP) students to research opportunities on campus which are then extended to their year abroad. IEP students are enrolled in a five-year dual degree program through which they pursue two simultaneous degrees: a B.S. in an engineering discipline, and a B.A. in a foreign language. In their 4th year they go abroad first studying for one semester at one of our partner universities in Canada, Chile, China, France, Germany, Italy, Mexico, or Spain, followed by a six-month internship in a company in the foreign country, in the second language.

The paper will discuss

- ☐ the context of educating engineering students for global careers
- ☐ the sequencing of a model of local to global research and internship engagement
- ☐ the academic framework, supervision and credit transfer guidelines for advisors
- ☐ examples of successful student engagement in various areas

Keywords

Global engineer, international engineering education, undergraduate international research opportunities, international internships, attribute of a global engineer

## Global Engineering Education Context

The need to educate globally competent engineers to meet the demands of the global engineering profession and market and the challenge to come up with related curricular reform has been emphasized by engineering educators[1], engineering societies[2], accreditation agencies[3] and globally operating companies[4] for many years. At the ASEE 2014 annual conference in Indianapolis, a workshop[5] led by Steven Hundley and Lynn Brown summarized the concerted efforts and outcomes of several years of research by the American Society for Engineering Education's Corporate Member Council, reflecting the voice of industry to define "The Attributes of a Global Engineer." The workshop summarized the process and results of this extensive undertaking to define attributes representing the desired competencies needed by engineers in order to effectively live and work in a global context.

The "Global Engineer project" which grew out of an ASEE special interest group linked with the

ASEE Corporate Members Council in 2008 and driven and supported by the Boeing company set out to define the special skills, knowledge, abilities and perspectives an engineer working in the global economy needs. A survey containing questions about the most important “attributes” of a global engineer was then translated into 13 languages and distributed through IFEES to members of engineering societies across the globe. After an analysis of the initial survey results and presenting preliminary results at the 2013 ASEE annual conference, the “attributes” were further refined by workshops and focus groups that met between 2012-15 at ASEE conferences, global colloquia and other engineering conferences throughout the world. Then the 20 attributes the groups agreed on[6] were organized by an ASEE special interest group (SIG) into 5 categories in which the attributes around the global effectiveness of an engineer could be grouped: Technical, Professional, Personal, Interpersonal and Cross-Cultural.

This paper is interested in showing how those desired attributes can actually be nurtured and achieved by an innovative engineering curriculum which integrates the humanities with a mandatory long-term stay abroad[7]. More specifically, it concentrates on showing how the complementarities within a sequence of domestic to global research opportunities (at our German academic partner, the TU Braunschweig) to an internship in a globally operating company in Germany is uniquely set up to foster the kind of attributes within our German IEP undergraduates the ASEE study has deemed crucial for engineers to function effectively in today’s global economy.

## Background

In the five-year dual degree International Engineering Program (IEP)[8] whose mission is to educate the global engineer, students are pursuing a B.S. in an engineering discipline, and a B.A. in a foreign language and they spend their senior year abroad at one of the IEP’s academic partner universities followed by a six-month internship in a company in the target country. Students in the rigorous IEP are not the typical group of engineers; rather they combine a strong interest in engineering, math and the sciences with an equally lively penchant for the humanities. They devote parts of their already packed engineering schedule to completing a full second Bachelor’s degree in a foreign language and then perfecting their technical, linguistic and cultural knowledge during a one-year immersion stay studying and working abroad.

To maximize the collaborations built between our partner universities, we have begun to set up with our technical partner university in Germany a 10-12 hour research experiences per week for students in the upper segment of the group going abroad. Those students typically are involved in research groups in their home campus department and then apply for a research project in a complementary institute at the German partner university. If selected by the head of the institute abroad, they will be supervised by a Post Doc or Ph.D. candidate in the institute and will also have monthly skype or email or phone meetings with their advisor at home. As part of the requirements on both sides, they need to present the findings of their work in German in their abroad institute, and also write a 10 page paper in English for their home advisor. If the grade they receive is satisfactory, they can receive 3 professional elective engineering credits for their work.

These pioneering and highly committed students are then also placed in internships in companies that – in the ideal scenario – offer an internship project where the students can apply their former academic research experience.

## Guidelines for a Research Project for IEP students at TU Braunschweig

Students of the University of Rhode Island (URI) International Engineering Program (IEP) typically stay at TU Braunschweig from October 1st to February 15th of the following year taking language, culture, history and sometimes engineering classes, all in German. They spend the next semester completing a six month industrial internship at a German company.

While staying at TU Braunschweig selected IEP students have the chance to conduct a research project in an Institute of TU Braunschweig. This research project allows the URI students to get a first-hand impression about typical German university life in one of the 65 research institutes which hones their technical skills on the one hand and on the other contributes to the intercultural learning aspect of the IEP. The project may be experimental, theoretical or simulative in nature. Where possible the topic should bridge research activities at TU Braunschweig and at URI. It is conducted during the *Wintersemester*, typically from mid/end October to mid February. The typical workload is 10 to 12 weeks with 1 to 1.5 days/week, i. e. approximately 120 hrs. total workload. Project results should be presented in a written report of approx. 10 pages (in English) plus an oral presentation of approx. 15 to 20 minutes in German. An attestation of the project with workload and grade is issued by the TU Braunschweig Institute head and transmitted to the major Professor at URI. URI IEP students receive credits, typically 3 CP, for a "special problems" course in their field.

The following guidelines were agreed on to support completion of a successful research project at TU Braunschweig (TU-BS) and the transfer of credits to URI.

**The people involved in a successful completion of the project are**

- The student (with a GPA of 3.3 or higher and enthusiastic about doing research)
- The engineering major professor at URI, who would be accepting the research project as special problem at URI
- The IEP director as facilitator between the two universities who advises the student with respect to choosing a suitable institute and may help contact the institutes
- The head of the institute or designated faculty at TU-BS where the research project is conducted, who selects the student
- A research assistant, typically doctoral candidate, at the respective institute to supervise the daily research work
- The instructor of the Advanced Technical German course of the Language Center at TU-BS where students prepare technical vocabulary and present their research in German.
- The TUBS/URI exchange liaison faculty member who may also assist in finding and contacting a suitable institute explaining the process.

## Process to secure a placement and follow-up

*Winter Semester at TU Braunschweig*

Conduct research project >> Student, research assistant

Skype/email once a month with URI faculty mentor to gauge progress >> URI faculty mentor

*First half of February*

Finalize Project, report results in German, write report in English and give oral presentation in German to research group >> Student, institute representatives

*Before student departure from TU Braunschweig*

Attestation of research project as special problem with workload and grade by institute professor >> TU-BS institute faculty

Send copy of project report to Director of IEP, and to International Office so that grade can be transferred to student transcript; send 10- page report to URI faculty mentor so that he can decide if and how many credits to transfer >> Student/ Int. Office URI faculty advisor

Needless to say that such the research opportunity in the university in Germany alone requires the most careful selection, matching of student interest, capabilities with the assigned tasks, strong mentoring from the home campus advisor and on site mentor, and, of course, an enthusiastic student with the drive and determination to succeed, even in a foreign environment and against potential obstacles.

## Student trajectories

Examples of students who participated in institute research on their home campus or did a domestic summer internship, and who then conducted complementary research at TU Braunschweig, followed by a six-month internship in a German company follow below:

1. *Computer Engineering & German dual major: From summer internship at Sensata Technologies (Attleboro, MA) to research at the Institute for Communication Networks at TU Braunschweig (Fall semester) to six-month internship at IAV (Gifhorn, Germany)*

In the summer of 2014 the student interned at Sensata Technologies (a company that develops sensors to ensure the safety in automotive, household, medical and other applications). He worked in the MSG division (microfused silicon strain gauge) on a graphical diagnostic tool for a differential pressure sensor based in Matlab. By the end of the summer he had a better understanding of what car sensors are made of and how each one has a system within itself to protect against errors.

From October 2014 until February 2015 the same student conducted research at the Institut für Datentechnik (Institute for Communication Networks) developing methods for detecting corrupted packets in a multi-nodal communications network and then retransmitting those corrupted packets. This network was being developed for fault tolerant critical applications such as wireless communications technology. The institute does research of this type for use with VW cars e.g. the communications network for the sensors in a car could be an application of this network.

The student is currently working at IAV (Ingenieurgesellschaft Auto und Verkehr), an automotive supplier in northern Germany. He is part of the mechatronics division specifically the team for 6 and 8 cylinder Diesel Audis developing another graphical diagnostic tool based in Matlab. This diagnostic tool helps to figure out what is wrong with a car based on sensor outputs. These errors can then be corrected within the car's ECU. An oversimplified example would be an airflow sensor which is reading very high during a drive because the sensor components are affected by the heat; this "error" can be corrected by reading a temperature sensor and shifting that sensor's output accordingly. The diagnostic tool is based in Matlab, a program the student got to practice using already at his summer internship so he is well versed in the creation of a GUI (graphical user interface) in Matlab.

If one were to analyze the learning curve from summer internship to research in a German institute to internship in a German company one can conclude that on the technical level, he learned at Sensata Technologies how an individual sensor works, how it has built-in methods for detection and correction of errors. At the Institut für Datentechnik he saw how these sensors might communicate with each other adding in fault detection and correction redundancies (so experienced a second layer of fault detection and correction that deals with the transmission of information). Finally, at IAV he experienced how sensor outputs are handled once they arrive at their destination (the car) adding yet another level of fault detection and correction within an integrated automotive system.

In addition, he experienced working in a German research team all the while taking German language, culture and engineering classes for his semester of study at TU Braunschweig which added a cross-cultural and linguistic layer. Due to the nature of his assignment – basically programming in more or less sophisticated ways – this computer engineering student did not get to experience real team work in his companies, more so in the research institute. Being tasked with programming at a company like Sensata (a mostly electrical/mechanical engineering firm) means working quite independently because most of the engineers do not care how the program works (its efficiency or optimization techniques) as long as it does work. At IAV the student also works quite independently but occasionally needs to get feedback from his colleagues, e.g. how his team wants a certain set of information displayed, in a histogram, a best fit line, discrete points, etc. In terms of integration into a German research team, his experience at the Institut für Datentechnik was more balanced, neither over- nor under-managed, structured yet with some freedom for exploration. Since it was technically more challenging it required feedback from team mates and his supervisor, so led to more back and forth. He was given an overarching task that lasted the entire semester, but because the system was very new to him and somewhat obscure he was both told how certain functions should operate but also given the freedom to make some of those decisions himself.

2. *Electrical Engineering & German dual major – from research in TU-BS's Institut für Nachrichtentechnik (Insitute for Communications Technology) to internship at ZF Friedrichshafen (a leading transmission and drive technology company)*

This student conducted his research at the Institute for Communications Technology assisting a PhD candidate to use speech processing to detect the emotion of a speaker's voice. His part of the project was to write a Matlab program which would take a recorded sample of speech, and process it to try and figure out the fundamental frequencies of the speech. He was given a well-documented algorithm to learn and put into code – for the first half of the project he analyzed the algorithm, learned how and why it worked, and programmed it into Matlab code – all this including the coding was done in German. He spent the latter half of his time researching and consulting with the project sponsor, trying to learn ways to improve the program through pre- or post-processing of the signal. In addition, he also attempted to implement some noise reduction into the code. Knowing the fundamental frequencies of speech is considered key to understanding the emotions involved. His program was a trial: the team was observing how a new method of fundamental frequency estimation would impact results. Throughout this time the undergraduate learned a good amount about signal processing, a theme in electrical engineering he had a great interest in and now had the chance to delve further into to see if it would make a potential career field.

At ZF Friedrichshafen AG, the technical part of his six-month project is much different from that at TU-BS. He works in a department that oversees the design and development of electronic control units for use in commercial vehicles. These electronic control units (ECUs) are pivotal in optimizing performance in transmissions systems, active suspension, and many more aspects of automobiles.  In short, their job is to tell the mechanical parts of these systems how and when to move. While the technical side of the electrical engineering skills put to use were very different, the student learned a lot about German work culture in Braunschweig that carried over to ZF. Learning to write and comment his code in German and picking up relevant technical vocabulary helped him gain a level of accomplishment and confidence that enables him to hold his ground in this more formal corporate environment when communicating with the members of his team.

3. *Computer Engineering & German dual major: From working in URI's IT department to research in the Institute for Communications Technology to internship at DB Netz*

The Computer Engineering & German dual Bachelor degree senior began working at the URI Engineering Computer Center during his freshman year, maintaining the hardware and software for all the lab computers and servers as well as general upkeep of the computer center. The specific tasks varied greatly, from the more complicated maintenance of URI's Linux-based servers, scripting administrative tools in Perl, and a custom WordPress installation for the engineering webpages to preparing Windows images to deploy to the lab computers. These tasks gave him a strong background in IT knowledge which is useful in any environment where computers are involved. Another aspect of his URI based work was providing technical assistance to faculty and staff in the engineering college through which he gained a great deal of experience interacting with team members and peers to solve various problems.

He continued to improve and utilize the skills he learned working at URI when he began his research at the Institute for Communication Technology (Institut für Datentechnik) at Technische Universität Braunschweig, where the research platform was based in a Linux environment. He worked in cooperation with German faculty and PhD candidates already involved in the project. Like all German IEPers he first took an intensive German Summer School course preceding the academic semester at TUBS and was then enrolled in courses to advance his proficiency in the German language (Advanced Technical German); civilization and history (Landeskunde) and Intercultural Partnership Course (IPP) which he took simultaneously while engaged in his research project.

After the Wintersemester (Fall term) in Braunschweig, the student moved to Frankfurt to begin his internship in the network division, DB Netz, of Deutsche Bahn (German Rail), one of the largest logistics providers in the world. His current project involves working in a multifaceted group, consisting of a managerial team and a technical team, designing a web application for internal company use. Given the team-based aspect of the project and the technical, programming side of the work, he is able to now apply the technical and team skills he learned and continuously improved through his work at the computer center (URI) and his research at TU-BS in a real corporate environment focusing on the needs of various departments within this large company. Through his experiences both in the US and in Germany, he has become a more competent individual in both his engineering field, German proficiency, cultural and cross-cultural knowledge and his professional abilities and interactions.

4. *Chemical Engineering & German dual major: From research in URI's Nanotechnology Lab to research at TU Braunschweig's Institute for Medicinal Pharmacy to internship at BASF in Ludwigshafen, Germany*

This Chemical Engineering & German senior was involved in Chemical research in three different labs—stretching across both the spectrum of scientific fields and different locations. His undergraduate engineering research journey took him from a project sponsored by NSF led by Geoffrey Bothun in URI's Bionanotechnology Laboratory trying to enhance oil spill treatment methods, to characterizing drug delivery systems under Professor Heike Bunje's guidance at the Institute for Pharmaceutical Technology at TU Braunschweig to attempting to increase the lifetime of a battery cell at BASF's Ludwigshafen headquarters.

At first glance these research topics seem to be vastly different, how could oil spills, pharmaceuticals and batteries possibly have anything in common? However, specific lab techniques indeed crossed over, just with different applications. The student used Dynamic Light Scattering in both university research labs to measure particle sizes in the nano range. He worked with dispersions, mixing two chemically dissimilar substances together by using the means of surfactants (in Dr. Bothun lab he tried to mix oil and water using "food grade surfactants", with Dr. Bunjes he assisted in emulsifying "water unsoluble" drugs into water using lipid nanoparticles). The project at BASF in the Process Research and Chemical Engineering department which has the student assemble and analyze lithium ion battery cells uses a very different technique - Impedance Spectroscopy – goal is to find out what can be done to make a longer lasting battery. But even here one could find a commonality or even complementarity:

In the case of the oil spills the student was trying to emulsify oil into water, two liquids that repel each other due to fundamental differences found at the molecular level—differences caused by charge. For the drug delivery systems the same idea was at work, trying to dissolve nonpolar ("evenly charged") drug into a polar ("unevenly charged") solvent. And of course, in his batteries research and experimentations he is trying to store this charge with as large of a capacity for as long a time as possible. With each experience he gained skills that he was able to apply to the next level, whether it was the use of a technical method or device, efficiently managing his time, communicating effectively with team members through daily interactions (first in English, then in German) on to presentations of his research results in German to his German institute team to a scientific paper summarizing the results in English for his URI faculty mentor to interacting in German with a team of researchers in a corporate setting at the largest chemical company in the world and managing his time under constraints like deadlines and stakeholder needs.

*Research in China – connecting the home campus with abroad*

Through our Chinese & Ocean Engineering IEP program a student's international research project became part of a larger agenda between the home campus and the campus abroad. This was the case for an Ocean Engineering & Chinese major who studied at Zhejiang University simultaneously pursuing research in the university's newly established Ocean College. This College received significant help from the University of Rhode Island department of Ocean Engineering to establish their curriculum and has been sending their faculty to our campus to learn from us while also receiving Ocean Engineering faculty to teach and help build the curriculum from scratch. In this scenario, the undergraduate researcher who had been trained at home in certain geo-technical methods and had taken the courses the host university wanted to "import," was even able to play a role in the process of curriculum transfer. The additional benefit for the student in this scenario was that the research experience in China made it easier for her to find an internship at Offshore Pipelines & Risers, Inc. in Hangzhou which is a start-up out of our academic partner university in China, Zhejiang University.

*Research at URI, at PUCV and at BASF in Chile*

We have begun to also set up research experiences at our new partner university in Chile, the Pontificia Universidad Católica de Valparaiso (PUCV) in Valparaiso, Chile, followed by internships in a Chilean company. One such example is the experience of a Chemical Engineering & Spanish IEP senior who worked as a research assistant for Dr. Gonzalo Ruiz Filippi, Associate Professor of the Biochemical Engineering School, and Deputy Dean of the College of Engineering at the Pontifical Catholic Univeristy of Valparaíso, in his Environmental and Biotechnology Laboratory. The student worked in Dr. Vinka Oyendel–Craver's Sustainable and Environmental Technologies Laboratory at URI in Spring 2014 in the area of "green synthesis of nanoparticles," focusing on the fabrication of silver nanoparticles in a sustainable and environmentally friendly manner during the spring semester of 2014. At PUCV he continued his URI research using the fabrication process developed at URI, to create silver nanoparticles and eventually copper nanoparticles, in Dr. Ruiz' lab in Chile. The question the group tackled was "where do the nanoparticles go after they are used, and what happens to them when they pass through our current water treatment systems?" There are many products currently on the market that use nanoparticles, e.g. sunblock and antimicrobial socks. Therefore, the idea was to find out where the nanoparticles went after a person who had used the sunblock took a shower, or after a person washed their socks that contained nanoparticles. Would they pass through the filters due to their extremely small size? And if so, how would they affect the water treatment process? Would they improve it with their antimicrobial properties, or pass through all stages of treatment untouched and eventually contaminate our drinking water? There was also the possibility that due to their unstable structure, (it is very difficult to separate the particles and then keep them separated at nano-size) they would clump back together, unionize, and form larger particles that would get trapped in the filters.

During the Spring semester 2015, the student is interning at BASF in Valparaíso in their Residuals Division focusing on liquid industrial residuals, also known as waste water. He has been assigned three independent projects: The first two projects, The Optimization of the Wastewater Treatment Plant and the Traceability of the Wastewater Treatment Plant, are to be completed at the same time. The idea of the first project is to study the water treatment process in detail and identify bottle necks, or areas where the process is slowed down, and innovate solutions to optimize the system and improve the overall treatment time. The goal of the second project is to develop a method to estimate the quality of the waste water at the end of treatment by taking a quick approximation early in the process. The idea is to encounter a relationship between the clarity of the water early in the process with the final overall quality of the water and use this method to avoid treating water that will not have a final overall quality the meets legal standards, ideally saving time and money on treatment the will not result in a desirable final product. The third project, to be completed after the first two, involves designing a sand filter as a primary treatment system to help optimize the overall water treatment process. He can put his experience as a member of URI's chapter of Engineers for a Sustainable World to work in designing a sand filter for waste water treatment. The student's work with waste water at BASF relates nicely to his research in the Environmental and Biotechnology Laboratory at PUCV in terms of waste water treatment. However, it differs in the fact that at BASF the group is not using nanoparticles in their treatment process.

## Conclusion

On the meta-level, going back to the "attributes of a global engineer" we postulate that the local to global research/internship sequence described in the examples above enabled the students to go way beyond learning new technical skills in a lab environment. They had to possess at least some of the following attributes (from the list of 20 mentioned in the ASEE study cited above) to successfully complete all three projects:

*On the technical level*, they had to demonstrates knowledge of project planning, management and the impact the project has on various stakeholder groups (team members, sponsors, clients, end-users)

*On the professional level*, they had to embrace "a commitment to quality principles/standards and continuous improvement" and to apply "personal and professional judgement in effectively making decisions and managing risks."

*On the personal level they had to have individual characteristics needed for global flexibility* including the "ability to think both critically and creatively," the "ability to think both individually and cooperatively"; they had to maintain "a positive self-image and positive self- confidence," "show initiative" and "demonstrate willingness to learn."

*On the interpersonal level they needed skills and perspectives to work on interdependent global teams such as* "functioning effectively on a team (understanding team goals, contributing effectively to the team, supporting team decisions, and respecting team members.)"

*On the cross-cultural level they had to demonstrate society and cultural understanding to embrace diverse view-points* including "an understanding of the ethical dimensions and business norms" and had to apply "norms effectively (in a specific industry, context, and country.)"

Furthermore they definitely had time throughout their five years of learning the German language and taking German culture and history classes as well as conducting their research and internships in a German environment, to develop "an international/ global perspective"; after their year abroad they will furthermore "possess fluency in at least two languages." The fact that they used their academic training in a particular field in various "concentrations' or applications in which a set of different fields came into play, also equipped them with the flexibility of mind to "embrace an inter-disciplinary/multi-disciplinary perspective."

References

[1] Downey, G. L., Lucena, J. C., Moskal, B. M., Parkhurst, R., Bigley, T., Hays, C., & Nichols-Belo, A. (2006). The globally competent engineer: Working effectively with people who define problems differently. *Journal of Engineering Education*, *95*(2), 107-122; Allert, Beate I., Atkinson, Dianne L., Groll, Eckhard A., Hirleman, E. Dan, „Making the Case for Global Engineering: Building Foreign Language Collaborations for Designing, Implementing and Assessing Programs in *Online Journal for Global Engineering Education* (OJGEE )Vol. 2 (2007) Iss. 2, article 1; Grandin, John M., Hirleman, E. Dan, "Educating Engineers as Global Citizens: A Call for Action: Report of the National Summit Meeting on the Globalization of Engineering Education, in *Online Journal for Global Engineering Education* (OJGEE) vol. 4 (2009) issue 1; Parkinson, A. The rationale for developing global competence. *Online Journal for Global Engineering Education*, vol. 4 (2009) issue 2.

[2] National Academy of Engineering. (2004). *The engineer of 2020: Visions of engineering in the new century*. Washington, DC: The National Academies Press, 2004.

[3] Michael K.J. Milligan, "The future of international engineering education and accreditation's role in improving quality and promoting innovation." Keynote at the 13th Annual Colloquium on International Engineering Education: Moving Forward, Nov. 4-7, 2010 Newport, R.I.; Shuman, L. J., Besterfield-Sacre, M., & McGourty, J. (2005). The ABET "professional skills"—Can they be taught? Can they be assessed?. *Journal of Engineering Education*, *94*(1), 41-55; Prados, J. W., Peterson, G. D., & Lattuca, L. R. (2005). Quality assurance of engineering education through accreditation: The impact of Engineering Criteria 2000 and its global influence. *Journal of Engineering Education*, *94*(1), 165-184.

[4] McMasters, J. H. (2004). Influencing engineering education: One (aerospace) industry perspective. *International Journal of Engineering Education*, *20*(3), 353-371; Bybee, R. W., & Fuchs, B. (2006). Preparing the 21st century workforce: A new reform in science and technology education. *Journal of Research in Science Teaching*, *43*(4), 349-352; Arlett, C., Lamb, F., Dales, R., Willis, L., & Hurdle, E. (2010). Meeting the needs of industry: The drivers for change in engineering education. *Engineering Education*, *5*(2), 18-25; Genheimer, D. R., Stephen, R., Shehab, D., & Randa, L. (2009). A survey of industry advisory board operation and effectiveness in engineering education. *Journal of Engineering Education*, *98*(2), 169-180.

[5] Hundley, Stephen, Brown, Lynn, "The Attributes of a Global Engineer: Implications and Opportunities for Corporate members," workshop W221, ASEE Annual Conference in Indianapolis, IN June 18, 2014 available at http://www.asee.org/public/conferences/32/registration/view_session?session_id=3964.

[6] See the list of the 20 attributes in Hundley, Stephen, Brown, Lynn, Fox, Patricia, Didion, Catherine "The Attributes of a Global Engineer: Purpose, Perspectives and Progress" in Proceedings of the ASEE Annual Conference, June 23-26, 2013, Atlanta, GA available at http://www.asee.org/flash/FlexPaperViewer.swf?PrintEnabled=true&ZoomTime=0.25&SwfFile=%2Ffile_server%2Fpapers%2Fattachment%2Ffile%2F0003%2F3165%2F6198.pdf.swf&FitWidthOnLoad=true&ProgressiveLoading=true&ZoomInterval=0.1&Scale=1&FullScreenAsMaxWindow=true&ZoomTransition=easeOut&FitPageOnLoad=false

[7] Grandin, John M., Berka, Sigrid, "Reforming American Higher Education: The University of Rhode Island International Engineering Program" in ADFL Bulletin 2014 Vol. 43, No. 1 (2014), pp. 23–44.

[8] For more information on the International Engineering Program see its main website at www.uri.edu/iep.

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# The Cordial Scientist*

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**Abstract**

Using the concepts of agency, voice, and authority[2], which lie at the foundations of learning, we argue for the necessity of unpreparing lectures, in opposition to the usual push towards more technologically sophisticated methods for preparation and delivery of content.

**Keywords**

Global experiences; disprepared lectures.

**Agency, Voice, Authority**

Several are the ways of teaching; and 3 are the foundations of learning: agency, voice, and authority[2].

Agency is perhaps the most immediate to the engineer: the learner needs to make herself capable of operating with the concepts acquired. Ideally, in order to execute an engineering project; or at least to grow to a higher level of understanding, and begin a course of study that will lead there, without throwing out the ladder after having climbed its steps. In a minimal, almost caricatural, version, agency can mean solving homework exercises and answering exam questions. Not necessarily irrelevant, as solution of problems correlates to understanding, this version becomes counterproductive when it replaces completely the more general idea of agency. The tail wags the dog, Goodhart's Law[A] rears its ugly head. In the infamous closed–book exam, teaching rules, and learning runs away. Whoever has ever heard of engineering done by an individual alone without books or references is free to feel piqued.

Voice implies in autonomy, a concept which goes beyond the act of speaking and asking in the classroom, although even these quotidian activities may be repressed via complex processes

*Being the translation from the Portuguese of a part of a book in preparation[1].

[A]"When a measure becomes a target, it ceases to be a good measure."

which by reasons connected to my cultural inheritance I am not capable of comprehending. The student needs to learn to talk about the subject with his own voice. This is as true in supposedly impersonal subjects typically studied by engineers as anywhere else. The minimal pre-requisite is simply talking — or writing. Its opposite is the unidirectional, hierarchical classroom, typical of Europe, especially the Septentrion,[B] at least until the 1960s; and to judge from the rumors of those that come back to the University of S Paulo after a junior year abroad, not there yet completely overcome. In the land of Carnival, the class where the instructor talks with the chalk, the chalk streaks the slate, the slate speaks to the student, and the students checks the cheat sheet in the cell phone, this class repeats the European tragedy — after the class is over, the distance evaporates in the coffee shop where professors and students call each other by the first name, only to return as a tropical farce in the next class. Also a requirement is the professor's voice — thus the importance of authorship, of papers, books, conference talk, at least as much for establishing the professor's voice as for the scientific content of the documents themselves.

Authority comes from the Creation, which only reveals itself by reflection, by experiment, by consideration of accumulated wisdom, and by recognizing and overcoming errors. Perhaps it is the thorniest concept for the gentile, especially the Meridional, oppressed by centuries of forced deference to political authority and to political intermediaries of the Word. Authority imposes itself by knowledge; by authorship while it renews itself continually; otherwise it dissipates into mere respect for the memory of the knowledge of the elderly. It differs from vulgar authority that subjects by the force of rules and the control of information. In the absence of autonomy, the professor and the text place themselves between the student and knowledge. A good teacher is one that doesn't muddle the students.

**Unpreparing lectures**

It becomes indispensable to unprepare classes.[C] The ready, coherent, irrevocable exposition distances the student from the reconstruction and appropriation of knowledge. The content is lost in following the logical, perfected development, which is made obscure by the consistency which is only visible a posteriori, and places bookish lore above the student's ability for daily comprehension.

Giving the student voice requires the professor to rebuild the investigation during each lecture — whether introducing a subject that's new to herself, or by means of perfectly reasonable deviations from the beaten track, where uncertainty is mostly theater. Thus the depth of science is freed, in the students mind, from the instructor's personal authority — it is only when the professor doesn't have all answers ready that the student re–acquires her voice.

* * *

The illusory security brought to the professor by knowledge numbered, weighed, divided in a correctly prepared lecture is counterproductive. Leaving aside the uncertainty concerning the effectiveness of new technologies[3], the question of how they can be used to improve the

[B]This may be completely lost in translation; archaic words help or hinder?
[C]Or disprepare?

execution of teaching methods that remove agency, voice, and authority, from the master as well as the student, is irrelevant. For technologies, new or not so new, can transmit information almost on their own. Before some adventurer grabs them, the university has to tear down the walls to continue as a locus of creation of real and relevant knowledge.

## Appendix: Some specific Brazilian experiences

The remainder of this paper is of interest only to those trying to deal with issues specific to Brazilian universities. The author will endeavor to translate it to the same awkward language as above upon request, if there is interest.

A expressão mais fundamental da agência, fora do momento da sala de aula, está na definição e controle, ainda que parciais, dos rumos de seu próprio currículo por cada estudante.[D] Os currículos rígidos e monotemáticos praticados na esmagadora maioria dos cursos da USP retiram da aluna a voz individual, em prol de uma uniformização de "critérios de saída" cuja função, se já houve, perde–se nos meandros da história. Mais do que eliminar a voz e agência do estudante, a invariância das disciplinas obrigatórias retira a autonomia da autoridade do mestre, relegado à condição de cumpridor de estruturas curriculares pré–definidas pelo estamento burocrático, de intermediador de conteúdos carimbados pelo patronato dos donatários do poder acadêmico, de estruturas de poder tão vagas e inacessíveis que nem a origem dos regulamentos é bem conhecida, e folcloricamente imagina–se provir do Planalto Central.

Desde 1994 o curso de Automação & Controle, especialidade da engenharia elétrica da Escola Politécnica, tem buscado se pautar por princípios opostos. Reconhecendo a diversidade de interesses dos estudantes, a multidisciplinaridade dos usos da engenharia de controle na vida profissional futura dos politécnicos, as sempre imprevisíveis demandas e necessidades do desenvolvimento tecnológico do país, e a riqueza de pontos de vista oferecidos pelos professores não somente da Escola Politécnica como da Universidade de S Paulo como um todo, o currículo reserva 2 ou 3 matérias em cada semestre durante os 2 últimos anos para optativas livres que podem ser cursadas em toda a universidade, não apenas escolhidas entre as matérias que através de seus docentes o grupo de pesquisa e centro de decisão sói oferecer aos "seus" alunos. Dentro do espírito de interdisciplinaridade e flexibilidade, o curso procura manter o conjunto das matérias obrigatórias a um mínimo que julga constituir a linguagem comum de todos os egressos da área, de forma a possibilitar que a dedicação às optativas não seja apenas nocional — para que o aluno possa efetivamente pensar fora das grades.

Após 20 anos de avanços e retrocessos, a Escola Politécnica aprovou a estrutura curricular chamada EC3, que contempla de maneira geral muitas das ideias resumidas acima. São 2 passos para frente e 1 ou 2 ou 3 para trás. Na implementação, infelizmente os interesses e visões locais dos donatários de grupos de pressão e ensino com frequência se sobrepujaram às intenções da Escola, logrando preencher grande parte dos espaços reservados a eletivas livres com matérias especializadas de interesse de laboratórios de pesquisa. Os obstáculos enfrentados na Politécnica são da mesma sorte que aqueles já encontrados nas 2 décadas anteriores pelo curso de Automação & Controle: essencialmente, cada departamento, por temor aos efeitos da iniciativa discente, busca controlar a totalidade do conteúdo oferecido a cada estudantes, e também resiste a oferecer seus conhecimentos a estudantes cujo currículo não controlam completamente — incluídos aqui tanto os departamentos da mesma unidade como os de unidades separadas, com algumas exceções.

A resistência à flexibilidade curricular não pode ser completamente atribuída ao reacionarismo, uma vez que a individualização curricular contemplada pelas reformas dos anos 1990, na Automação & Controle, e agora nos anos 2010, na Politécnica como um todo, não é ideia nova. A flexibilidade proposta é não mais do que uma pálida reflexão dos sistemas curriculares dos "liberal arts colleges"[4], que são nos Estados Unidos o padrão de ensino de alta

[D] As matérias fora da área são tão ou mais raras na humanidades do que nas ciências, e em ambos os casos na maioria aparecem como disciplinas "de serviço", com títulos utilitários "para" ou "aplicadas a", que são quase caricaturas da ciência original.

qualidade voltado para a formação do ser humano como um todo e não apenas com vistas à preparação para uma prática profissional que atenda a necessidades específicas do mercado de trabalho momentâneo. Longe de ser uma novidade, o sistema baseado em disciplinas eletivas se origina na segunda metade do século XIX, notadamente com as reformas curriculares introduzidas em Harvard por Charles Eliot, e é um conceito válido inclusive para cursos profissionais como o de engenharia.[5]

As grades curriculares constrangem a agência, a voz, e a autoridade de estudantes e professores simultaneamente. É necessária a busca de métodos que libertem a academia do enjaulamento pelos currículos padronizados e pré–fabricados, bem como pelas práticas de ensino hierarquizado que colocam o professor designado pelos donos do poder como detentor único da Verdade. Mesmo porque hoje o controle do fluxo de informações é cada vez mais difícil.[E] A sequência de invenções, nos 2 últimos milênios aproximadamente, do códex, da minúscula carolíngea, da imprensa, e da máquina copiadora, permitem ao próprio estudante ir direto à página relevante da fonte primária, ignorando o intermediário que não agrega valor ao conhecimento escrito. Com a chegada da internet, terminou de vez no Brasil a era das formas tradicionais de controle da informação, do Index Prohibitorum, do auto–da–fé, do dólar–livro, do DIP e do DOPS. Com um pouco de vigilância continuaremos livres do Departamento de Orientación Revolucionaria e da Grande Firewall da China. A devoção ou saudade dessas formas de controle se afigura como explicação mais plausível para a insistência no ensino unidirecional, não–interativo, do que o desconhecimento das tecnologias que permitem transformar a vida na sala de aula em uma recriação conjunta do saber; pois as tecnologias são armas milenares na luta contra o monopólio estamental da informação na qual a rede mundial de computadores desfere apenas o coup–de–grâce.

## References

[1] Felipe Pait. *Folhas do Butantã; ou, O Cientista Cordial*. Real Imprensa Imaginária do Boupinel, 2015 (no prélio).

[2] Jessica M. Deshler and Elizabeth A. Burroughs. Teaching mathematics with women in mind. *Notices of the AMS*, 60(9):1156–1163, October 2013.

[3] E.R. Tufte. *The cognitive style of PowerPoint*. Graphics Press, 2003.

[4] Heloisa Pait. As faculdades de artes liberais americanas: Raízes, adaptações e desafios atuais. In Cristina Pecequilo, Erica Simone Almeida Resende, and Eugenio Diniz, editors, *Os Estados Unidos No Mundo Atual*. Editora Juruá, Curitiba, 2010.

[5] Felipe Pait. Currículos de engenharia norte–americanos. *Revista Engenharia*, 71(620):27–30, maio 2014.

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[E] Talvez por isso mesmo entre membros do estamento burocrático e do patronato universitário brasileiro encontra–se uma simpatia maior por propostas anti–liberais de controle dos meios de comunicação, e por limitações alfandegárias ao comércio de bens e ideias, do que entre a população em geral. Tese especulativa, a conferir.

# Integration of Software in Structural Engineering Education

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## Abstract

In the work place today, software is typically used by the structural engineer to analyze and design most elements of a structure. There is a wide variety of software available to the structural engineer, allowing the engineer to analyze and design micro, macro and even all elements of a structure. In fact, it is common today for consulting firms and contractors to use multi-discipline software that inputs the project, including the structure, in a three dimensional model and through the use of add-on software and/or third party software analyze and design the structure. As educators, how do we, or for that matter do we, bring this software to the classroom or laboratory. It allows our students to solve complex problems and potentially makes them more marketable. However, if all we teach is the software, who answers the question "Do the results make sense?" As of today and it may change in the future, the computer does not have a professional engineering stamp and the software provider implicitly states that it shares no liability and make no guarantees concerning the use of the output from its software. Is it possible to make tens of thousands of input entries and have no mistakes? This discussion presents the author's view on how to balance the use of software with the "archaic" methods of our ancestors in teaching structural engineering courses.

Keywords: Structural Engineering, Software, Education

## Background

Wentworth Institute of Technology has been a fixture in Boston, Massachusetts for over 100 years. The Institute has graduated hundreds of students in the civil engineering technology field (BSCET) and graduated it first class of students in civil engineering (BSCE) in August, 2014. The Institute is well respected for its hands-on approach to education. As a graduation requirement, all civil engineering and technology students are required to have two – one semester long co-op experiences. In an ever changing curriculum, the courses currently offered to students focusing in structural engineering are shown in Table 1:

**Table 1-Institute's Undergraduate Structural Engineering Courses**

| Course | | Title | Lecture | Lab | Course Credit Hours |
|---|---|---|---|---|---|
| CIVE 372 | Junior Year<br>Fall Semester | Structural Analysis (CORE) | 3 | 0 | 3 |
| CIVE 440 | Junior Year<br>Summer Semester | Structural Steel Design<br>(ELECTIVE) | 3 | 0 | 3 |
| CIVE 450 | Senior Year<br>Spring Semester | Reinforced Concrete Design<br>(ELECTIVE) | 3 | 0 | 3 |
| CIVE 650 | Senior Year<br>Summer Semester | Capstone – Senior Design Projects<br>(CORE) | 1 | 6 | 4 |

A prerequisite for the structural analysis course is the succession of the statics and strength of materials courses taken by the students in their sophomore year.

## Introduction

In education today, the credit hours and contact hours in the degree programs are being decreased. Typically, structural analysis focuses on hand calculation techniques developed by our ancestors to solve problems. The Work Place solves these same problems using sophisticated and expensive software. As educators, where is our focus, hand calculations using methods developed by our ancestors or software? The question:

***HOW MUCH, IF ANY, SOFTWARE SHOULD BE USED IN STRUCTURAL ENGINEERING EDUCATION?***

While the focus of this paper deals with structural analysis, much of the discussion is appropriate to structural design.

## Brief History of Computing

The following discussion presents a very brief history of computing on our planet, Earth. This discussion in a large part reflects the authors 40 plus years' experience in the field of structural engineering. It is not intended to be a fully documented history of computing.

- Abacus[1] – One of the earliest known methods of computing can be traced back to about 2400 BC. The inventors were the Babylonians and Egyptians. The version of the abacus seen today was developed by the Chinese around the second century AD with a similar version developed independently by the Aztecs of South America. The abacus can add, subtract, multiply, divide and raise numbers to powers with the big draw back that those are the only math functions it could do.

- Slide Rule[2] – It took almost 4000 years to come up with the next significant breakthrough in computing, the slide rule. The slide rule was invented in the 17$^{th}$ Century AD by Edward Gunter, William Oughtred and al. It was a major breakthrough in computing in that it did may mathematical functions to include multiplication, division, natural logs and logs to the base 10, trigonometric functions, and square roots. However, it did not add or subtract and perseverance was needed to place the decimal point in the correct position.

- Computer Age[3] – Commercially, the computer age started in the 1960s with the main frame computer. International Business Machine (IBM) was one of the leaders in the development of the main frame computer and as a civilization the dark ages were left behind and civilization moved into the light. The main frame computer preformed just about any mathematical function. However, it required significant space often occupying the basement of a campus building or a floor of a business. It started with the use of punched cards to enter data but quickly moved to interactive CRT terminals. While it opened up the ability to solve problems only dreamed of solving in the dark ages, it was expense to use. A typical scenario in this time frame was to use the entire computer budget in an overnight run that resulted in finding the solution to structure being investigated was useless. Thus leading to the expression "garbage in – garbage out". Also, in this time frame, the electronic calculator became commercially available. Texas Instruments and Hewitt Packer were some of the earlier manufactures of these electronic instruments. Like the main frame computer, the electronic calculator performed almost all mathematical functions. The increase of the work force productivity as the result of the computer and electronic calculator was significant. As an example, the solution of engineering mathematics involving trigonometry went from the use of 10 place logarithms to two bottom pushes on the electronic calculator. Initially, these calculators were not programmable and many did not provide a hardcopy of the results. Further development lead to the personal computers and then the laptop computers. Today, the laptop computers used are orders of magnitude more powerful than the initial mainframes allowing engineers to solve large complex structural systems at their desks in seconds. Left behind in this discussion of the computer is the development of software to use with the computer. At the start, the user developed the software but today there are hundreds of commercially available software packages to perform almost any structural engineering task. Again, welcome to the light, the “golden age” of structural engineering.

## Structural Analysis – BC (Before Computers)

Structural analysis before computers was performed based on the methods of our analysis developed by our ancestors. If the analysis involved the development of a shear and moment diagram for a uniformly distributed load on a simply supported beam, the solution was trivial. Using Newton’s first law of motion, the reactions at the support are calculated. Then, using free body diagrams, the shears and moments for points anywhere on the beam could be developed.

If the problem was a three dimensional space frame that might represent a building, the solution was indeterminate and much more complicated. A typical solution to this type of problem in the dark ages, before computers, was to break the structure into two-dimensional pieces and solve the indeterminate two-dimensional frame using a method of analysis such as moment distribution. This method of analysis was developed by Hardy Cross[4] in the late 1920’s. This approach was apparently too late for use in the design of the empire state building and waited to after the great depression for significant use in the design of high rise buildings. This method of analysis uses a stiffness approach. It utilizes an iterative approach that yields moments at supports and intersection of members but does not directly yield displacements. The major advantage of this approach is that the iterative approach to the problem avoids the solution of simultaneous equations. Other indeterminate structures solutions, such as slope deflection, require the solution of simultaneous equations. The solution of the many simultaneous equations developed for a three dimensional space frame was one of the deterrents in the use of these methods. Method such as double integration, virtual work, moment area and conjugate beam were used to find deflections. In essence, as educators, these and other similar techniques are the predominate topics taught in the structural analysis course. All of the methods described above require significant time and effort to formulate solutions.

## Structural Analysis – AC (After Computers)

With the advent of computers and the development of software to efficiently utilize the computer, the solutions to the simultaneous equations that held the engineer back in the dark ages have disappeared. Regardless of the method used to develop the simultaneous equations, the laptop computer on the engineers’ desk can solve structural analysis problems that have tens of thousands of degrees of freedom in a matter of seconds. The computers along with the developed software solve problems that an engineer could not solve in a life time. General structural analysis and design software such as GT STRUDL[5], STAADPro[6], SAP2000[7] and RISA-3D[8] have allowed the structural engineer to analyze and efficiently design structures that were next to impossible to analyze in the era before computers. The question that needs to be asked is how the engineer knows that the computer solutions are “right” or at least reasonable. Is it possible to enter thousands of line of input and not make a mistake? The adage mentioned at the start of the computer discussion “garbage in – garbage out” is still appropriate.

## Is the Future Now?

With the introduction of three-dimensional modelling systems such as Autodesk's Revit[9] or the Bentley equivalent, the architectural-engineering industry takes another step forward. The entire structure is modelled in three dimensional while a data base is established to include items such as beam sizes, lengths and material types. The model is not limited to just items related to the structural sub-discipline of engineering but is multi-disciplined. It includes items such as mechanical ductwork sizes/ run locations and equipment; as well as, architectural items. The multi-discipline model can be used as a check for interferences, such as checking to see if a run of ductwork hits a steel beam. From a structural engineering standpoint, the structural information can be transferred to a structural analysis and design program (e.g. Autodesk's Robot[10] or Bentley's STAADPro[6]). The structural analysis is based on assumed shapes and the structural analysis and design program can refine the design and transfer the revised sections back to the three-dimensional model system. Figure 1 shows a sample of a 3-D model generated in Autodesk Rivet and Figure 2 shows the results of the transfer of this information to Autodesk Robot. Today, two-dimension drawings can be established by cutting planes in the three dimensional model. Tomorrow, it is likely that the three-dimensional model may be universally accepted as the "model of record". The "method of the future" is very much a "black box" approach. Again, is it possible to enter thousands of lines of input and not make a mistake?

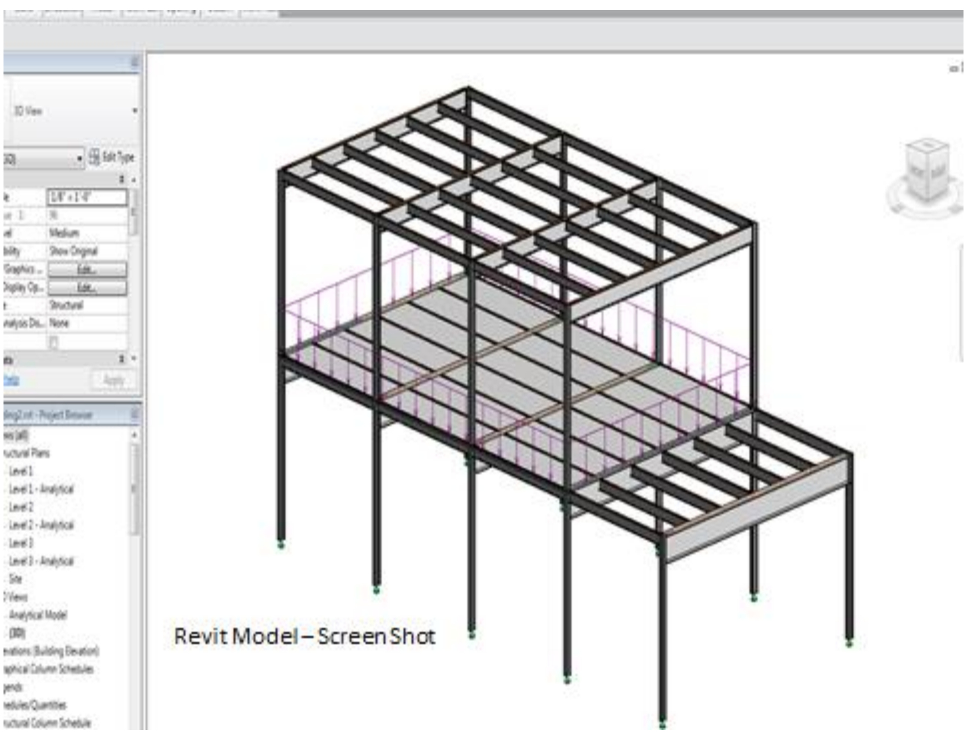


**Figure 1 – Revit Model**

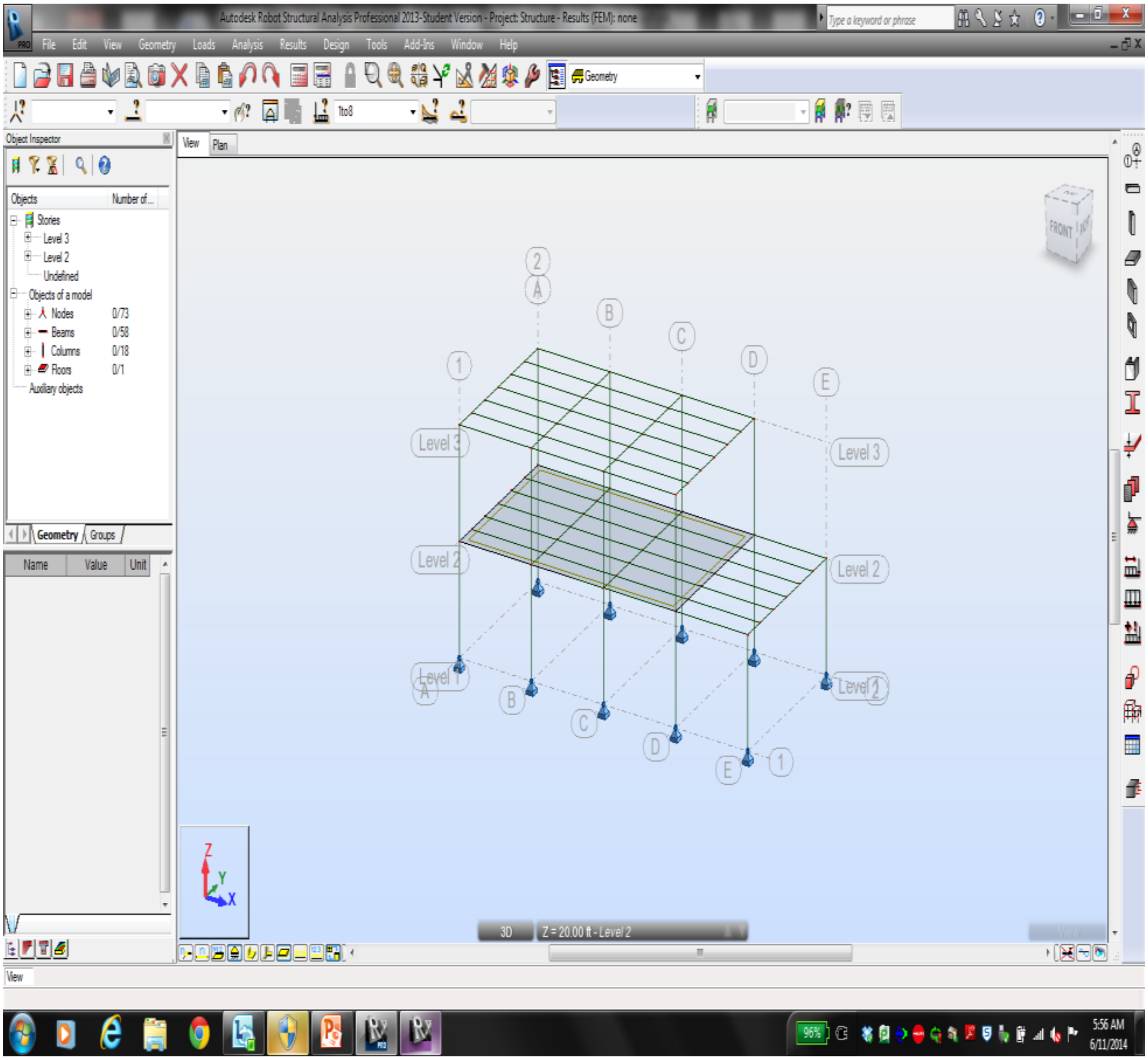


**Figure 2 – Structural Information Transferred to Robot**

## Responsibility for Correctness

The question is who is responsible and liable for the correctness of the computer solutions and the correctness of the three dimensional model. Is it the computer and the software or the Engineer of Record? Below is a typical example of a software disclaimer found on almost any commercial available software:

"While {fill in software vendors name} has taken every precaution to utilize the existing state-of-the–art approaches to ensure the correctness of the analytical solution techniques used in this program, the responsibility for modelling the structure, inputting data, applying engineering judgment to evaluate the output, and implementing engineering drawings remain with the engineer of record. Accordingly, {fill in software vendor's name} does and must disclaim any and all responsibility for defects or failures of the structure in connection with this program use."

Furthermore, the computer used to do the analysis and design does not have a professional engineer's license. Consequently, the computer is not able to stamp the drawing and become the Engineer of Record.

Therefore, the liability and responsibility lies with the Engineer of Record. The Engineer of Record who places her/his professional engineering stamp on the drawing is responsible for the design of the structure. In addition, the use of the three dimension building information modelling (BIM) to order material is likely the liability of the engineering company that produced the model. As example, if a BIM system was used to make a mill order for structural steel by the Contractor, who is liable if the model is not correct? In a "design-bid-build" contract, a mistake in the model could cost the engineering company more than its design fee for the contract.

## Education Choices

While it appears simplistic, it comes down to three basic choices as to how the use of software is addressed in the curriculum.

## TEACH NO SOFTWARE

While at first glance, this approach seems unrealistic. In many ways, the teaching of an undergraduate level structural analysis course has not changed significantly in fifty years. Most of the concepts taught in this course are the classic methods of analysis formulated by our ancestors and date back, in some cases, to Galileo. This approach limits the marketability of the student. It impedes research and the solutions of complex structural problems. It limits that student's ability to tackle complex problems and structures in the Senior Capstone Projects Course. The reality is that teaching the use of software in a course limits the number of other topics that can be addressed in the course. Compounding this issue is the educational-trend to reduce the number of credits needed to graduate, reduce faculty-student contact hours, and focus on a more general curriculum. Consequently, the approach to teach no software in a course is supported by a surprising number of faculty.

## TEACH ONLY SOFTWARE

The approach to teach only software, while tempting initially, appears to be riddled with deep concerns when studied further. Teaching only software and not the classic methods of structural analysis may make the students very proficient in the use of the software. The students can do research and solve complex problems. However, the students likely will not know if the answers generated by the software make sense. As a society, the results generated by an electronic calculator are accepted without question. As educators, the hope is the students will look at the results from the calculator and asked themselves if the results relating to the problem being solved make sense. As discussed earlier, the commercially available structural analysis and design software is sophisticated and complex. Error notices are generated on a regular basis and distributed to the end users. In addition, the level of the input, even with the help of graphic user interfaces, is enormous. Is it possible that all of the input is correct? It just takes one load applied in the wrong direction to invalidate the entire analysis and design. Most people would agree that using software without a general knowledge of the expected results is a bad idea.

## TEACH SOME SOFTWARE

Teaching some software along with the classic analysis methods in a course makes the students more marketable, allows research and the solution of complex problems but at the same time makes the student able to answer the question -"Do the answers make sense?". In addition, it helps the curriculum meet ABET – General Criterion 3 - Student Outcomes (a-k)[11], specifically the following Student Outcomes:

- j: Knowledge of contemporary issues.
- k: Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The challenge is to find a way to introduce software into the course without reducing content. To date this has been accomplished by making software available to the students with some direction of use by the instructor in the classroom. With this approach, the students require a large independent effort external to the classroom to be proficient in the software. The Civil Engineering Department at our Institute developed and implemented a Design Studio Lab (DSL) for use in the 2014-2015 school year. This experiential studio linked several of the Civil Engineering sub-disciplines in a series of two-two hour studios/labs and one lecture per week (three credits). Four Civil Engineering sub-disciplines participated in this experiential studio with the desired goals of; gaining additional knowledge in a specific Civil Engineering sub-discipline, performing experiments and exercises in a sequence that illustrate the multi-discipline interaction that typically occur on Civil Engineering projects, developing a better understanding of the role of each sub-discipline in the practice of Civil Engineering and emphasizing the need for communication, collaboration and cooperation between Civil Engineering sub-disciplines. The use of software has been introduced into this course. In the fall of 2015, the Wentworth EPIC curriculum will be started. It is intended that more software use will be brought into these EPIC design studios.

## Conclusion

The conclusion is apparent that the students need to be taught the classic methods of analysis developed by our ancestor in order to determine if the answer generated by the computer/software are reasonable. It is certainly desirable to introduce the students to relevant software in the classroom. The challenge is to find the means and vehicle to introduce the software without diminishing course content of the classic methods. Regardless, the software results should be used by the students to check the results of the classical analysis. In industry, the process is reversed. The software will likely be used to analyze and design the structure and classic methods used to answer the question "Does the computer results make sense?".

## References

1. History of Computers and Computing, Calculating Tools, The Abacus, http://history-computer.com/CalculatingTools/abacus.html
2. The Oughtred Society, Slide Rules History, http://www.oughtred.org/history.shtml
3. The Yale Herald, From Mainframe to Laptop, The History of Computers at Yale University, http://www.yaleherald.com/archive/xxvi/11.6.98/exclusive/
4. Leonard K. Eaton, Hardy Cross and the Moment Distribution Method, http://www.emis.de/journals/NNJ/Eaton.html
5. GT STRUDL, Structural Modelling, Analysis, and Design Software, Intergraph, http://www.intergraph.com/assets/pdf/GT_STRUDL_Brochure.pdf
6. STAAD-Pro, 3D Structural Analysis and Design Software, Bentley, http://www.bentley.com/en-US/Products/STAAD.Pro/
7. SAP2000, Integrated Structural Analysis and Design Software, Computers & Structures, Inc.: Structural and Earthquake Engineering Software, http://www.csiamerica.com/products/sap2000
8. RISA-3D, Structural Engineering Software, RISA Technologies, LLC, https://risa.com/p_risa3d.html
9. Rivet, Building Design Software, Autodesk, http://www.autodesk.com/store/revit-structure
10. Robot, Structural Engineering Software, Autodesk, http://www.bhphotovideo.com/c/product/1079242-REG/autodesk_547g1_wwr111_1001_robot_structural_analysis_professional.html?gclid=CLn_2L60vMQCFeJj7AodxWwAPA
11. ABET, Criteria for Accrediting Engineering Programs Effective for Reviews During the 2014-2015 Accreditation Cycle, General Criterion 3 – Student Outcomes, http://www.abet.org/eac-criteria-2014-2015/

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# Numerical Simulation as in Integral Component of Dynamics Problem Solving

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## Abstract

The engineering faculty at Roger Williams University are committed to training students to use modern computer-based tools when performing engineering analysis. But achieving this is a tall order, as engineering courses are already jam-packed with essential technical material and any hindrance to delivering this material is unwelcome. Likewise, we routinely pay lip service to the necessity for students to double-check their work, yet we provide students with few tools for systematically accomplishing this. This paper describes an effort by the author to integrate solid modeling into a *Dynamics* course by requiring numerical validation of symbolic solutions to homework problems. The students solve traditional homework problems using free-body diagrams, equations of motion, pencils and calculators; but then must demonstrate that their answers are valid through an independent check. Students construct solid models in SolidWorks© to duplicate the geometric and inertial properties of the problem, and then use the Motion Analysis, a SolidWorks Simulation add-in, to create a motion study duplicating the conditions of the problem. Students may place dynamically updating dimensions to determine distances or may generate graphs, e.g. velocity versus time, to study motion characteristics. As a direct result, students are able to independently validate their symbolic solutions with numerical simulations. This paper will provide a detailed description of the use of SolidWorks in a sophomore level *Dynamics* course offered spring 2012-2014. This paper will present examples of student work and assess the benefits and challenges associated with this teaching method.

## Keywords

Dynamics, Simulation, SolidWorks, Self-check.

## Introduction

The faculty in our engineering program are committed to achieving ABET objective *k. an ability to use the techniques, skills and modern engineering tools necessary for engineering practice*. However, an isolated, introductory *Computer Applications for Engineering* course in the freshman year does not alone achieve this educational objective. We believe *objective k* is only achieved by four-year vertical integration of computer applications as engineering tools. But this is challenging in practice, as engineering courses are already packed with essential technical material and any encumbrance to delivering this material is unwelcome. The classical mechanics course (*Dynamics*) described in this paper is an effort to satisfy the two conflicting goals of building skills while maintaining content. Other authors[1,2] have cataloged the challenges of achieving this objective.

The literature shows that many instructors use some form of computer-aided simulation of problems[3] and some further employ problem solving software and interactive computing[4,5,6,7,8]. *Dynamics* is a required course for all students in the fourth semester of our eight-semester general engineering program. This course is offered to the entire sophomore class in two sections with a population of thirty to forty students each.

In prior reports[9,10], I described my efforts to completely transform this course into a computer-based learning experience where problems and even class notes were taken via computer, similar to a course described by other authors[11]. The central vehicle to this effort was MathCAD; a computer aided engineering application that allowed for symbolic manipulation and numeric simulation. The transmogrification of MathCAD in its Version 14 release caused me to abandon its use and return to a traditional chalkboard classroom in spring 2009. Frustrated, but committed to pursuing this objective, I began to employ SolidWorks[12] motion studies in 2009 as a numerical tool to compliment theoretical problem solving. In the subsequent years I developed and enhanced the incorporation of SolidWorks so that it is now an essential component of the course.

## Challenges

The primary challenge to this approach is building student competency in SolidWorks. There is scarcely enough time in the course for engineering mechanics content, leaving no class time for SolidWorks training. Our program incorporates an Engineering Graphics and Design course in the first semester that provides sufficient prerequisite skills in SolidWorks for the majority of the population. Dynamics, offered in the fourth semester, must overcome gaps in preparation that have opened due to the passing of time from the first to fourth semester and for transfer students without prior experience in SolidWorks.

To provide instructional support without dedicating precious class time, I created a library of narrated video demonstrations. Each video guides the viewer keystroke-by-keystroke through the SolidWorks application to create a SolidWorks simulation of each of the forty-three in-class example problems. The simulation must duplicate the mechanical conditions of the problem and produce a numerical result for an output parameter. This result is compared to theoretical analysis produced by algebraic manipulation of equations and computation on a hand-held calculator. Each video demonstrates how to extract numerical results from the simulation and compares these to hand-calculated results, finding remarkable agreement. Students follow the videos in the school's computer laboratory listening to the audio on individual headphones. They are often seen repeatedly rewinding and replaying the video while simultaneously constructing a simulation of their own similar but distinct homework problems. To define this term, the problems are similar in that both are, for example, projectile motion problems, but the figures, parameters and unknowns are distinct.

## Benefits

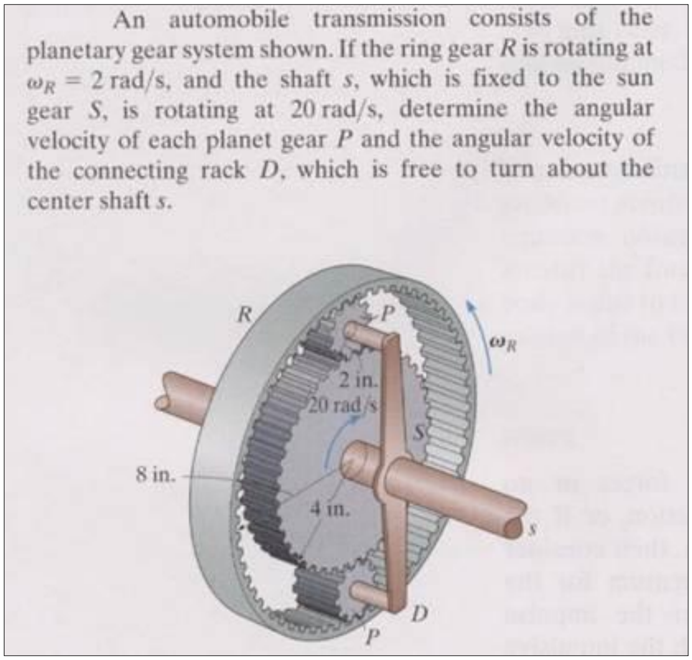


FIGURE 1 PLANETARY GEAR TRAIN HOMEWORK PROBELM

The Dynamics course is a traditional lecture format in which I perform live demonstrations with mechanical props, derive relevant formulas and work example problems on a chalkboard. Students complete weekly homework sets in groups, with each group assigned five to six problems. As the example in Figure 1 shows, the problem sets, are relatively challenging; requiring five to seven hours weekly. Each student in the homework group is responsible for completing three "initial solutions" and one "numeric check". The "initial solutions" are traditional paper-and-pencil solutions of the assigned homework problems using the student's hand-held calculator to perform computations. There is little novelty in the initial solutions; student work resembles student work of ten years ago and even resembles the homework I submitted as an undergraduate student quite a few years before that.

The novelty is exhibited in the "numeric checks", where students must simulate homework problems in SolidWorks by constructing solid models duplicating the kinematic and dynamic conditions of the problem. Students must then use this model to check their own work or the work of their peers. The following paragraphs describe the primary benefits of this activity to student learning.

## Kinematic Visualization

As a two-dimensional pictorial description is brought to life by the student's own hand; these assemblies are immediately useful for visualization. By dragging the mouse, the student witnesses

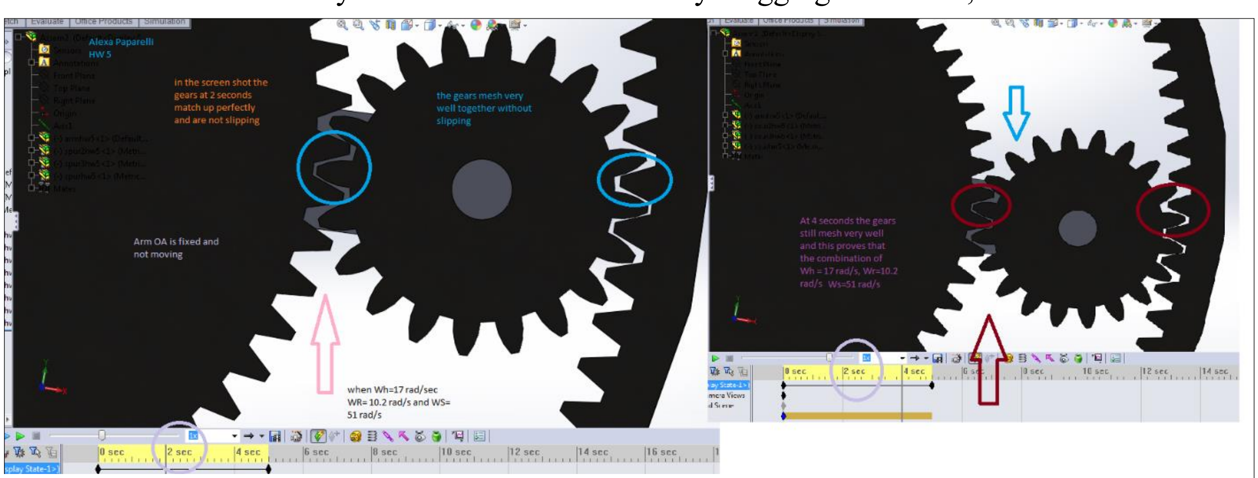


FIGURE 2 PLANETARY GEAR IMPLEMENTED IN SOLIDWORKS

the motions as gears spin, links move, bodies come into contact and range of motion limits are reached. This is particularly useful in complex kinematic problems as shown in Figure 1. Students often struggle with visualizing the motion of the planetary gear system. The simulation shown in Figure 2 requires several hours to build, and in the process students must select the appropriate kinematic mate to implement the motion. Selection of the wrong mate either causes a simulation error or the gear teeth to pass through each other during simulation. A properly built gear system will be pleasing to watch as gears enmesh and planet gears revolve around the sun gear. I expected that this would in itself be gratifying and educational for the students.

## Motion Studies

Once the problem kinematics are established, students move to the *Motion Study*, a rich set of SolidWorks features allowing students to generate motion and analyze the results. Figure 4 shows a student submission of a motion study implementing a multiple pulley problem shown in Figure 3. The inset graphs on Figure 4 are the results of a motion study selected by the student to demonstrate agreement with theoretical results produced by integrating angular acceleration twice with respect to time. In this case, the student has selected two graphs to ascertain "how far has wheel B spun when it stops". A student may not immediately recognize that a body with a positive initial velocity but increasingly negative acceleration will eventually stop, but the motion study shows convincingly that this is the case. The student has selected to show the angular displacement versus time and the angular velocity versus time plots. The student found the time that the velocity crosses zero as the red vertical line on both graphs and reads the angular displacement at that time.

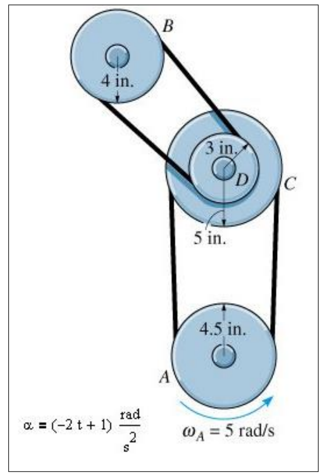


FIGURE 3 PULLEY PROBLEM

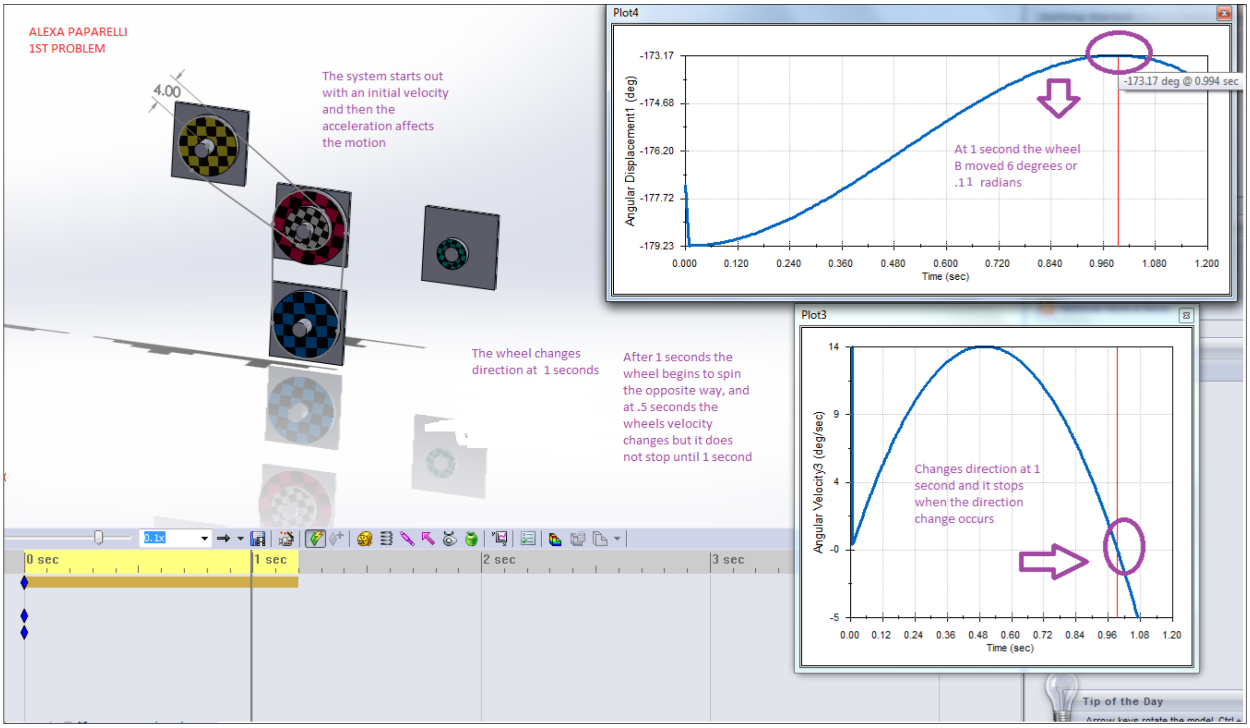


FIGURE 4 MULTI-PULLEY PROBLEM CONSTRUCTED IN SOLDWORKS

## Back of the Book Answers?

Although we may debate the wisdom of providing “back-of-the-book” answers to homework problems, we would likely agree that back-of-book answers are rarely available in engineering practice. Rather, successful engineers have developed the skill set necessary to employ various techniques to check their own work. In ABET documents we claim a portion of this class satisfies ABET objective *i. a recognition of the need for, and an ability to engage in lifelong learning* due to the training this course provides in self-checking.

Each group is required to develop a numerical simulation that checks the work of the other students in the group. As shown in Figure 5, a student has simulated the motion from the textbook problem and stopped the simulation at the specified instant in time. Also seen in Figure 5 is a block of text added by the student stating “Tip velocity when bar was horizontal was 172in/s which is 14.25ft/s. Calculated value was 14.32ft/s.” Note also that Figure 5 is a kinetic simulation of the rod falling under the effect of gravity, whereas the previous figures demonstrated only kinematic simulation.

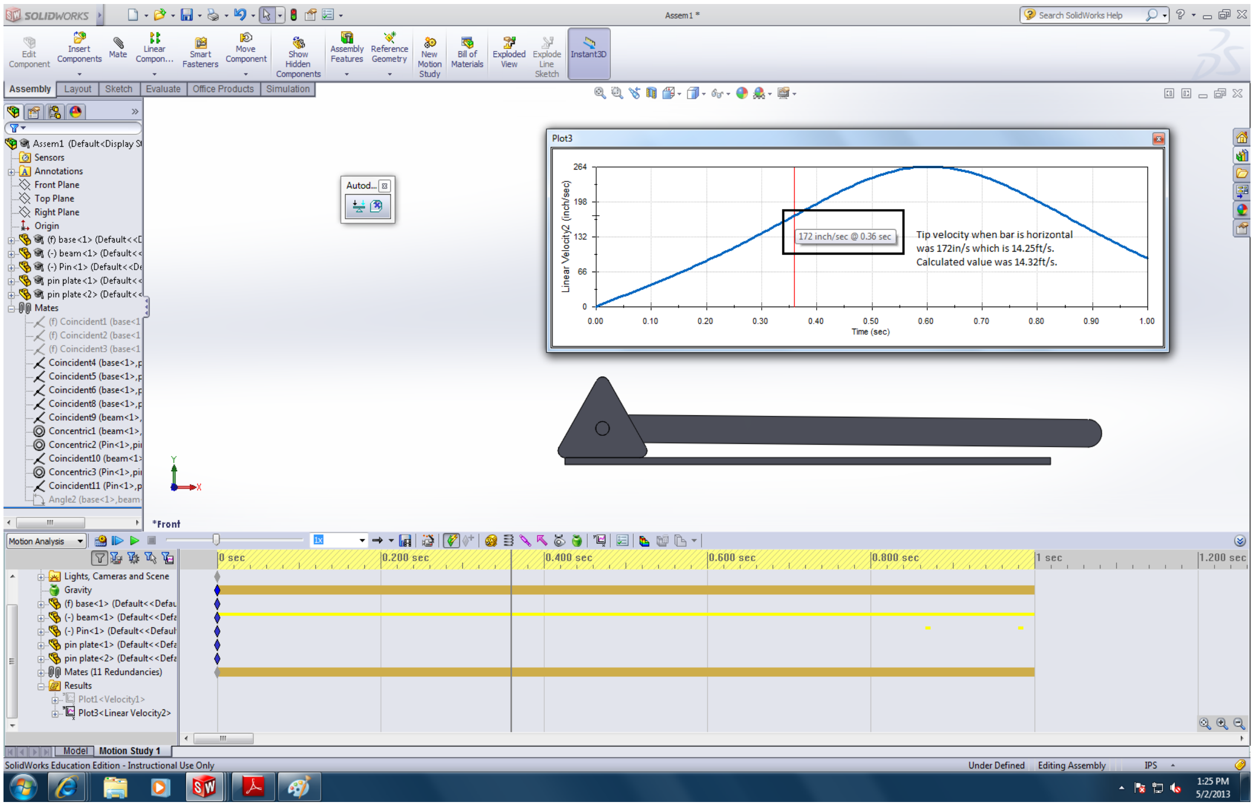


FIGURE 5 SOLIDWORKS MOTION STUDY SHOWING AGREEMENT WITH THEORETICAL SOLUTION.

Training engineers to devise their own means of teaching themselves is critical to an ABET accredited program, yet it is not clear that traditional homework assignments effectively produce this outcome. The numeric simulation is an alternative means of producing an answer, and neither the symbolic solution nor the numerical solution is as convincing in isolation as when the two methods produce the same result. Students recognize the potential of the simulation to produce erroneous results and often initially produce completely different results than they calculate. There is a subtle moment that students experience when they can find nothing else wrong with their simulation and start to believe that the error must be in their calculations. These students have never had the capability to prove themselves right, and I expected they would find this experience exhilarating.

## Skills

A final benefit is exercising and enhancing our student's skills in SolidWorks. We expect our seniors to use SolidWorks extensively in our capstone senior design, but our students learn SolidWorks formally only in their first semester. By the fourth semester Dynamics course they have already become a little rusty. If we do not require students to use SolidWorks as an integral part of their intermediate coursework; we should show little surprise when they proclaim as seniors that they have forgotten it all.

## Results

The four benefits described above are simply conjectured by the author. A survey was administered to students having just completed the Dynamics course in the spring of 2013 and

2014. Figure 6 presents data from an anonymous survey (inexpertly) designed by myself and administered to students at the end of the semester. Of the 110 students registered, 101 voluntarily completed the survey. The survey consisted of twelve Likert scale questions in 2013 and eleven in 2014. One question was removed as redundant, one question was reversed keyed, and the wording of the final question was modified to alleviate some of the issues cited in an earlier publication[13] from the 2013 data.

Adhering to the format suggested by others[14], Likert scale results are presented as a percentage of respondents centered at "neutral", with agreement with the prompt on the left in green and disagreement with the prompt on the right in red. The total percentage of responses to the left and to the right of "neutral", i.e. the sum of "strongly agree" and "agree" is shown as a label on each side. To limit "Acquiescence bias" one-fourth of prompts were keyed in the negative direction.

The survey only indirectly measures the effectiveness of the video library. In retrospect, it may have been valuable to include a direct question about the video library. Students were also asked to report the number of hours they spent on SolidWorks each week, responses were: Mean: 3.77, Mode: 3, Maximum: 12, Minimum: 1, Standard Deviation: 1.90, N: 101.

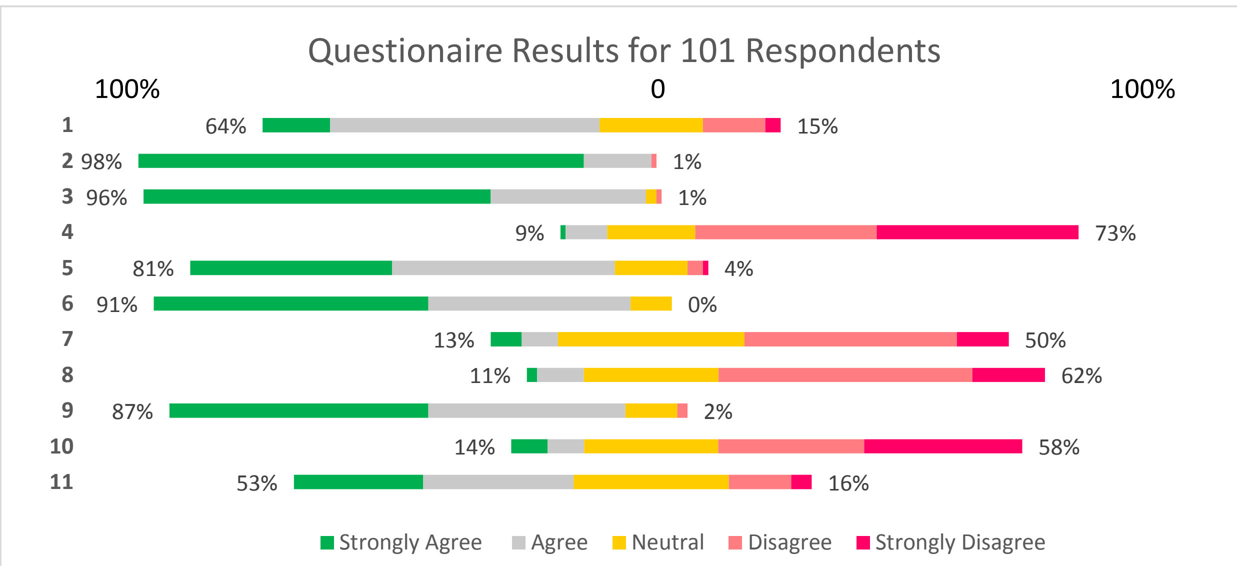


FIGURE 6 LIKERT SCALE RESPONSES TO ELEVEN SURVEY QUESTIONS

This section will consider the questions in order and discuss both the rationale for the question and my interpretation of the responses.

1. *My prior coursework prepared me to use SolidWorks in this course.* For the majority of respondents, prior coursework is a full semester of *Engineering Graphics and Design* three semesters prior and a single project in *Statics* one semester prior. Students indicated agreement by a margin of approximately 4:1, and this is interpreted as general satisfaction with the prerequisite structure but with significant room for improvement.
2. *My use of SolidWorks improved as a result of this course*. This question directly tests one of the conjectured benefits. Overwhelming agreement (98%) indicates to the author that the

exercises provide an appropriate challenge to students to expand their proficiency in SolidWorks.

3. *SolidWorks is a good tool for performing numeric simulations.* This question tests the suitability of SolidWorks to this use. Overwhelming agreement (96%) suggests to the author that SolidWorks is an appropriate tool for generating numeric results that are comparable to theoretically derived results.
4. *SolidWorks should be removed from the course or made optional.* This question tests overall validity of this initiative. Students disagree with this statement by an 8:1 margin suggesting that a strong majority believe the course is better with SolidWorks than without.
5. *SolidWorks helped me envision the problems better.* A test of the "kinematic visualization" result, eighty-one percent agreement including thirty-nine percent strong agreement suggests that SolidWorks is effective in helping students envision problems.
6. *I feel confident I will be able to use SolidWorks in future courses because of the use in this class.* No disagreement suggests students have gained sufficient confidence in SolidWorks to use it in courses later in the program.
7. *The time invested in SolidWorks is not proportional to the benefit.* The mean time spent per week reported by the students was 3.77 with a mode of 3 hours per week. The response of only 10% in strong disagreement and 13% in agreement indicates relatively large ambiguity in the student population. Whereas the previous responses clearly indicate there are perceived benefits, the population is not so well convinced the benefits are worth the significant time investment.
8. *I didn't really trust SolidWorks, I could always fudge a number to get the answer the others got.* This exact sentiment was expressed by some students in prior years and was included here as a quantitative measure of its prevalence. A margin of 5:1 disagreement suggests that this phenomenon is less prevalent than I had feared.
9. *The ability to verify my own solutions was rewarding to me.* Included to test the conjecture that SolidWorks was better than "back of the book" answers. 87% agreement suggests this intended consequence is achieved.
10. *I liked/hated building the SolidWorks models.* The 2013 prompt *I liked building the SolidWorks models* was changed to *I hated building the SolidWorks models* in 2014. I have removed the 2013 data from this question as combining the data sets by "flipping" the scale would have dubious validity. There were 43 respondents to this prompt in 2014.
11. *I started to trust the SolidWorks result more than my hand calculations.* About 3:1 margin of agreement indicates some progress in instilling confidence in students that the simulation results are both valid and useful.

## Conclusions

Survey results indicating levels of satisfaction exceeded the author's expectations and indicate that the project is worth continuing. Despite a significant time investment reported by the participants (an average of 3.77 hours per week), a strong majority believe it should be retained as a requirement in the course (Q4). The ability to check one's own work (Q9) is both a new and important skill that can benefit students significantly when introduced in the sophomore year. All of the conjectural results described in the first section were confirmed by direct survey. The author concludes that the inclusion of SolidWorks not only improves the teaching of Dynamics, but strengthens the entire engineering program by equipping students with the tools for lifelong learning early in their career.

We plan on continuing this use of SolidWorks in the *Dynamics* course and may expand its application to other courses. The results of Question 1 show there is room for improvement in the preparedness of students for this experience. We particularly need to address the special needs of transfer students who may get transfer credit for a graphics course using another application, (e.g. AutoCAD), and therefore will have no preparation for SolidWorks before taking the *Dynamics* course. We will also refine the questionnaire for the spring of 2015 to test the perceived value of the tutorial videos.

## References


1 W. Whiteman, K. Nygren, Achieving the Right Balance: Properly Integrating Mathematica Software Packages into Engineering Education. Journal of Engineering Education, July 2000.

2 B. Hodge, W. Steele, A Survey of Computational Paradigms in Undergraduate Mechanical Engineering Education. Journal of Engineering Education, October 2002.

3 A. Mazzei Integrating Simulation Software into an Undergraduate Dynamics Course: a Web-based Approach. Proceedings of the 2003 American Society of Engineering Education Annual Conference and Exhibition.

4 R. Flori, M. Koen, D. Oglesby, Basic Engineering Software for Teaching (“BEST”) Dynamics. Journal of Engineering Education, January 1996.

5 C. Demetry, J. Groccia, A Comparative Assessment of Student Experiences in Two Instructional Formats of an Introductory Materials Science Course. Journal of Engineering Education, July 1997.

6 Phillip J. Cornwell, Dynamics Evolution - Chance or Design. Proceedings of the 2000 American Society of Engineering Education Annual Conference and Exhibition.

7 D. M. Fraser, R. Pillay, L. Tjatindi, J. M. Cace, Enhancing the Learning of Fluid Mechanics Using Computer Simulations. Journal of Engineering Education, October 2007

8 R Stanley and G. DiGiuseppe, An Efficient Way to Increase the Engineering Student’s Fundamental Understanding of Thermodynamics by Utilizing Interactive Web Based Animation Software. Proceedings of the 2010 American Society of Engineering Education Annual Conference and Exhibition.

9 M.R. Stein. A Classical Mechanics Course in an Electronic Classroom: Challenges and Rewards. Proceedings of the 2009 American Society of Engineering Education Northeast Section Annual Meeting. April 2009. University of Bridgeport, Bridgeport, CT.

10 M.R. Stein. A Classical Mechanics Course in an Electronic Classroom: Challenges and Rewards. Proceedings of the 2007 American Society of Engineering Education Northeast Section Annual Meeting. April 2007. University of Rhode Island, South Kingston, RI

11 P. Boyle, Electronic Course Packaging for Statics and Dynamics: A review of Effort, Reward and Potential. Proceedings of the 2007 American Society of Engineering Education Annual Conference and Exhibition.

12 © SolidWorks ©2014 Dassault Systèmes SolidWorks Corp. Waltham, Massachusetts, USA http://www.solidworks.com

13 M.R. Stein. Numerical Simulation as in Integral Component of Dynamics Problem Solving IMECE2014-37472. Proceedings of the ASME 2014 International Mechanical Engineering Congress & Exposition IMECE2014 November, 2014, Montreal, Quebec, Canada

14 Naomi B. Robbins, Richard M. Heiberger, Plotting Likert and Other Rating Scales, 2011 Joint Statistical Meetings - American Statistical Association. Miami Florida, July 30th, 2011

## Matthew R. Stein

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# A Highly Portable Enhanced Password Protection Environment

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## Abstract

Nowadays, passwords have become an important tool for authentication and identity verification. Passwords provide the necessary security for bank accounts, social network accounts, etc. In this paper, we introduce an environment that uses a recursive algorithm to calculate the various encryption times and the required time a brute force algorithm will take to crack such encryption algorithms. Furthermore, this tool is highly portable, which supports any operating system and any hardware to calculate the probability of the decryption times. Thus, the user can enhance his password protection using the proposed environment.

## Keywords

Password Protection, Encryption, Brute Force, Decryption, Security Tools.

## 1. INTRODUCTION

With the tremendous grow of electronic transactions, authentication using passwords became a major component of any system. The more the facilities available to the user, the greater the number of passwords the user has to deal with. The introduction of large number of passwords for a single user creates significant confusion and the whole process becomes cumbersome. However, there are now easy and simple methods that have been developed to deal with the increasing number of passwords; thus making our life much simpler. The major concern is if passwords lead to other security issues, why do we use them? Exposure of user's private and confidential matter might lead to financial fraud or loss, public humiliation or any other kind of harm. The level of destruction that can be caused by disclosure of user's secretive information depends on the data which the individual is protecting by the use of the password. For example, hacking of a company's account might lead to leakage of the organization's trade secrets, financial data, target market, future plans, etc. People generally prefer passwords over smart cards, technologies with fingerprint identification, and scanning technology with retinal due to the ease of use and lower cost of the former. The password is considered as a collection of diverse typescripts that confirms the user's identity. The card number, username, electronic mail address, account are employed along with passwords. Though the former protects the distinctiveness of the individual and prevents exposure of his/ her personal information. The latter helps to identify the individual[1].

*A. Password Cracking:*

Although passwords are one of the most important tools for guarding information, the advancement in technology has made hacking of systems and breaking of password codes much easier. There exists a thin line of difference between the two terms: Hacking and Cracking. Password hacking refers to a user gaining access to a computer system, whereas cracking refers to breaking off the codes. The process of fracturing passwords to get illegal access to user's personal information or computer is termed as 'Password Cracking'. There exist a number of different methods and sources which can be effectively used to crack passwords. The most widely used technique is the brute force application using dictionary or guessing the word based on common and exposed words. Today, password cracking has become so common; that if any user types "password cracker" on Packetstorm or Passwordportal.net, the site will display various tools that could be easily applied to figure out passwords. Moreover, password cracking has become one of the favorite topics among authors who write articles. For example, the article which is titled "Security Focus article Password Crackers - Ensuring the Security of Your Password" explicitly addresses the methods of password cracking[7]. Furthermore, it discusses the use of social engineering for the purpose of cracking passwords which made it possible even for the common man to figure out passwords. The attacker needs to gather a bit of information about the individual whose account they want to hack. The article lists out all the steps in details that lead to password cracking. Sniffers have also been employed lately in this matter. They help in decoding the raw data that is transferred across internet. They can track all the information which a person sends across the net including his/ her password, bank details, etc.

*B. High Level of Security:*

Most successful techniques in password cracking contain all the alien and rearward words, so that nabbing a password becomes easier. Moreover, the simplest way to expose a password is by requesting the concerned person for the same by making some excuse. On the other hand, the best way to avoid hacking or cracking is by never sharing your password with anybody. The strength of a password varies from case to case. In some cases, it offers high level of protection, whereas in other cases it seems it is just the starting point. To increase the strength of a password, people generally make use of encryption and one-time password techniques. Mangling of the password in order to protect it from sniffers or other onlookers, so that nobody is able to decode it during transmission across the net is known as encryption.

In order to enhance the password security, users can adopt Bravenet Password Protect tool. This tool enables users to generate and protect up to 50 user accounts. It is also involved in the use of server-side authentication, creation of custom error pages, etc. Many other similar tools have been developed which perform different functions in relation to password security. One such example is the online form 'Password Generator'. This produces a series of codes that could be attached to a user Ht access file. For people who do not have an admission to a CGI-BIN, Kit, Password Protecting technique offers services such as Password Protect a web page, generated login form, gate keeper, and produced random passwords.

A master password is employed by password management software. It enables greater protection of user's password automatically entering the undisclosed encrypted strong password for user's account. This solves the twin problem of the user – now neither he/ she will have to memorize each and every password, nor will have to enable the 'remember password' option on the internet; which is potentially very dangerous and leads to password cracking or hacking. These protection services are available in various forms and versions[4, 5].

MyLOK throws away the user's anxiety regarding storage of password solutions using a cloud technique, after it gets converted. RoboForm Desktop 7 is the best tool to be considered when it comes to fill up of web forms. This tool possesses some limitations which can be overcome by an application of RoboForm that is called 'Everywhere.RoboForm'. Everywhere 7 is one of the most widely accepted tools, since it enables the users to install and synchronize RoboForm Desktop on all of their personal computers.

Password is popular software among all the Mac appreciators. 'KeePass Password Safe' is a well acceptable tool due to its compatibility with almost all the phones'OSs including: Android, Blackberry, PalmOS, etc. Moreover, it performs well on Mac, Windows and Linux.

Examples of some other password saving choices that do not call for the need of dedicated software are – Clipperz. It is a well-known password manager that operates online. It hides the identity of the user by creating secret and secure links in a short time. 'Mitto' is similar to secure systems which use password as defense such as log in installed in the tool bar.

Given a choice to choose any one of all the given options, the users must go for KeePass. It is free of cost and is compatible with Windows, Linux, iOS and Mac OS X. KeePass helps in the generation of a distinct password among the websites. Furthermore, it generates different password each time the user logs in. User can search for the passwords quickly and a complex tree-like structure can be maintained of the folders using KeePass.

For most of the people, it is simpler to keep the same password everywhere than to use password manager. You can keep all your unique usernames and passwords in a very secure database, which is encrypted using KeePass. This database is kept behind a single pair of username and password. KeePass does not save the password database on the cloud as in the case with LastPass. Although placing it in the Dropbox is possible, there is a feature in KeePass that generates random password itself, and thus the user does not have to think about a new random password. Moreover, the person has the facility to keep his/her master password and username in a User Account Control (UAC), which is a prompt protected function, and thus needs an administrative access of any key logger to record it.

## 2. ORGANIZATIONS AND NETWORK ADMINISTRATORS

By enacting strong policies related to passwords, the websites' managers can make difference in security and make it better. Hence, every organization must inculcate password policies into their organizational policies. Regular password updates must be enforced. Proper training and lessons must be given for how to protect their data from online hackers' attacks. Inexperienced users must be trained about best practices to be followed for passwords. Moreover, resources through intranet must be available for securing network and passwords. Ultimately, both password and security policies must be integrated and should be made accepted by everyone[2].

To make sure that people are using strong passwords, the system admins must use proper measures. An expiration date for passwords must be kept in a flow in the whole organization.

The accounts should be locked after 3-5 unsuccessful password attempts. Moreover, the access to these passwords must be kept limited in the organization. To have stronger protocols for authentication more secure password files, updated operating systems must be used. At last, whenever a new account is created, the default password must be changed quickly[6].

TrueCrypt is one of the strongest and most resistant encryption tools for consumers and is also open source. It can work with lesser security options, but requires a higher level of setup. However, this tool will protect users' passwords even if they possess a secret file, and were enforced to give away the password.

If someone wishes to transmit a secret message via open network without anybody noticing anything suspicious, Steganography is the tool to be used. It uses bits to encode data into normal carrying files such as images, so that only the recipient could decode it. If the users are unable to use any special tools that could hide files from unwanted access to their computers, there exists certain Window tweak that is low security but can secure the user from giving away personal and confidential data into unsolicited hands. There is a simple option in the properties of any file through which it can be made hidden provided the "Don't Show Hidden Files" option when is checked in the View button. Further, a tool known as Life Hacker Reader Sean can make use of a blank name to hide the folder[3].

## 3. BRUTE FORCE ALGORITHM

A recursive algorithm to brute force a string can be one of several algorithms such as MD5, SHA1, SHA256, and SHA512. Also, the additional add-on to the string could be a SALT value. Within the program, the user can define this value. Traditionally, it is a random 40-128 byte value, but for demonstration of how it can add additional protection, a simple addition from the user will be added. It can easily make the Brute-Force less operative by obscuring the encoded data. Thus, it will be hard for the attacker to expose the data. The most important point of measuring the asset of any encryption method is the time. How long can the attacker take to expose the encoded data? This technique was represented based on the Brute Force search tool, the universal issues-solving method of itemizing all contenders and examining each one.

## 4. THE RECURSIVE ALGORITHM

The Flowchart in Figure 1 shows how the recursive algorithm works on the brute force for decryption. Checking the array length is the first step in initializing the brute force algorithm. We use a stored procedure for counter stamp in order to check for the change in the array length. The flag value is displayed based on the key that is matching values of the array. Multiple iterations take blade to decipher the whole code. The brute force attack utilized in this algorithm, which makes the whole algorithm decipher faster based on the raised flag values and using a counter stamp. A closer look at the data memory section of the enhanced mid-range shows the registers are controlling the peripherals and I/O ports are accessed by reading or writing to specific data memory addresses. This mapping of peripherals to memory address greatly simplifies learning how to program the enhanced mid-range PIC.

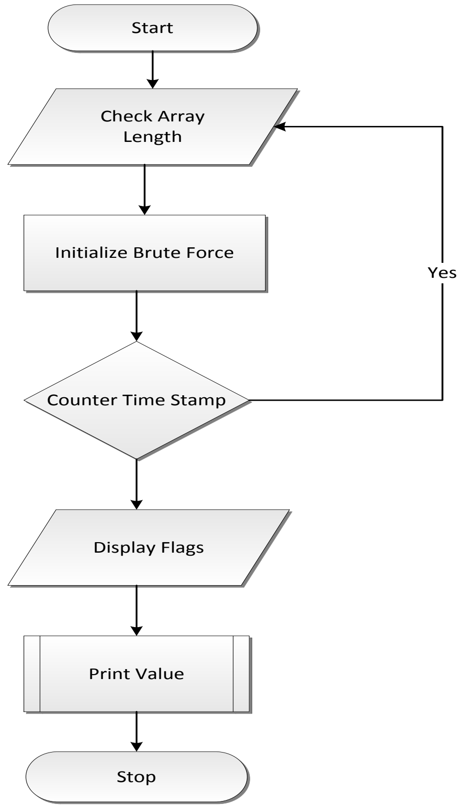


Figure1: Flow Chart of the Recursive Algorithm on Brute Force algorithm

## 5. SIMULATION EXPERIMENTS

Table1 shows various encryptions and the bit length being decrypted. The simulation was implemented using .NET framework for longer bit sizes on a computer with a quad core processor, and windows 8.1 operating system. The tabulated data shows accurate estimations for the required encryptions.

The principles of brute force string that is matched are quite simple. We must check for a match between the first characters of the pattern with the first character of the text. If they do not match, we move forward the second character of the text. After that, we compare the first character of the pattern with the second character of the text. If they do not match again, we move forward until we get a match or until we reach the end of the text. Because the first character of the text and the pattern do not match, we move forward to the second character of the text. Now, we compare the second character of the text with the first character of the pattern. In case they match, we move forward the second character of the pattern comparing it with the "next" character of the text. Just because we have found a match between the first characters from the pattern with some character of the text, does not mean that the pattern appears in the text. We must move forward to see whether the full pattern is contained into the text.

| Bits | Total Iterations | Time Taken | Algorithm |
|---|---|---|---|
| **1000000** | 78498 | 00:00:00.8925925 | Brute Force |
| **1000000** | 78498 | 00:00:00.0680448 | Eratosthenes |
| **1000000** | 78498 | 00:00:00.0410274 | Sundaram |
| **1000000** | 78498 | 00:00:00.0420275 | Atkins |
| **1000000** | 78498 | 00:00:00.0230142 | Atkins Optimized |
| **10000000** | 664579 | 00:00:00.7074686 | Eratosthenes |
| **10000000** | 664579 | 00:00:00.5553717 | Sundaram |
| **10000000** | 664579 | 00:00:00.6604359 | Atkins |
| **10000000** | 664579 | 00:00:00.4172764 | Atkins Optimized |
| **30000000** | 1857859 | 00:00:02.2154694 | Eratosthenes |
| **30000000** | 1857859 | 00:00:01.3498962 | Sundaram |
| **30000000** | 1857859 | 00:00:01.7111325 | Atkins |
| **30000000** | 1857859 | 00:00:00.9476313 | Atkins Optimized |
| **60000000** | 3562115 | 00:00:04.2558236 | Eratosthenes |
| **60000000** | 3562115 | 00:00:03.4372806 | Sundaram |
| **60000000** | 3562115 | 00:00:04.2388190 | Atkins |
| **60000000** | 3562115 | 00:00:02.4065895 | Atkins Optimized |
| **70000000** | 4118064 | 00:00:03.8966904 | Eratosthenes |
| **70000000** | 4118064 | 00:00:03.1110649 | Sundaram |
| **70000000** | 4118064 | 00:00:03.9406178 | Atkins |

Table 1: Comparison of brute force and other algorithms

We compared four algorithms which are Eratosthenes, Sundaram, Atkins, and Atkins Optimized to Brute Force algorithm. Table1 shows that the Brute Force algorithm stands longer in term of decryption process from the first iteration (78498). We increased the number of bits and the number of iterations for more than one cycle in order to know who comes after Brute Force attack. The results show that Atkins Optimized algorithm can be considered as second choice for the user.

Figure 3 shows a window form developed to decrypt a password with various encryptions. A variable time stamp with the amount of approximate time required to decrypt a password is generated. This tool will allow users to generate encryptions on any operating systems and get an estimate of the time analysis for the decryption process using various encodings that we have talked about earlier in the paper.

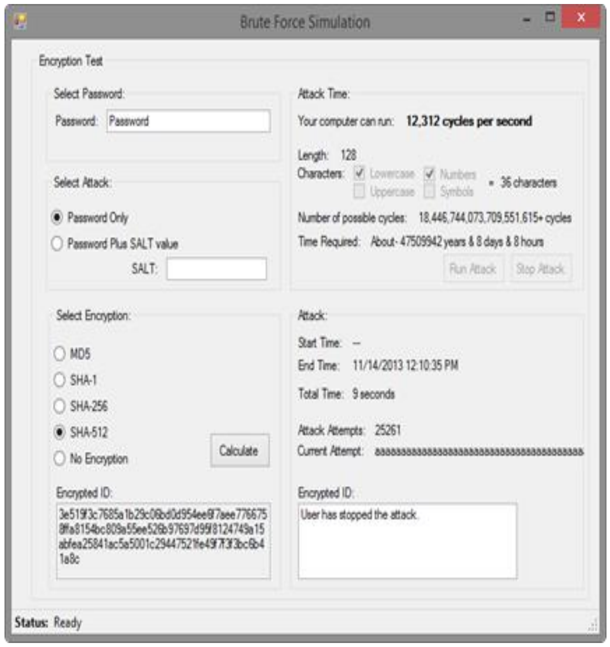


Figure 3: Brute force simulator

## 6. CONCLUSION

In this paper, we developed a highly reliable tool to calculate the various encryption times and the amount of time a brute force algorithm will take to attack encryption algorithms. Moreover, this tool is portable and can run in any operating system and a combination of any hardware to calculate the probability of the decryption times. Consequently, an individual user or a corporate can enhance their password protection using the proposed tool. Furthermore, the presented tool is highly scalable and is portable to different homogenous and non-homogenous environments.

## References

1 El-Bakry, Hazem M., and Nikos Mastorakis. "Personal identification through biometric technology." 9th WSEAS International Conference on Applied Informatics and Communications (AIC'09), Moscow, Russia. 2009.

2 Griffith, E. (2011, 12 06). Password Protection: Password Recovery and Control Tools. Retrieved 06 12, 2013, from http://www.pcmag.com: http://www.pcmag.com/article2/0,2817,2368988,00.asp

3 Errico, Stephen. "Systems and Methods for Accessing Secure and Certified Electronic Messages." U.S. Patent Application 12/555,909.

4 Zukerman, E. (2013, 02 01). Tools for the paranoid: 5 free security tools to protect your data. Retrieved 06 12, 2013, from http://www.pcworld.com: http://www.pcworld.com/article/2026561/tools-for-the-paranoid-5-free-security-tools-to-protect-your-data.html

5 Trapani, G. (n.d.). Best Free Ways to Protect Your Private Files. Retrieved 06 12, 2013, from http://lifehacker.com: http://lifehacker.com/391555/best-free-ways-to-protect-your-private-files

6 Wright, Steve. PCI Dss: A Practical Guide to Implementing and Maintaining Compliance. IT Governance Ltd, 2011.

7 Cliff, A. "Password Crackers-Ensuring the Security of Your Password. “Security Focus, Retrieved September 10 (2001): 2005.

# The Design of Lower Limb Exoskeleton Device as an Accessory to Portable Harness Ambulatory System for Assisted Mobility

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## Abstract

Due to the increase in life expectancy of elderly individuals, there is a greater need for investigations that will enhance their quality of life (e.g., independence and mobility). For elderly individuals, as well as stroke survivors, a Portable Harness Ambulatory System (PHAS) prototype, developed at the University of the District of Columbia, may prove to be a convenient and effective way for a home based posture and gait rehabilitation. For the current prototype, the addition of sensors and brushless DC motors to the PHAS system will allow ease-of-use (i.e., motion intent will be sensed) with minimal human interface. Furthermore, the use of a prototype lower limb exoskeleton may help patients recover and/or ambulate safely without the fear of falling or risk of injury. Further investigations include the assessment of the prototypes, control of a lower limb exoskeleton, and its synchronization with PHAS for effective gait rehabilitation in a home environment.

**Keywords:** Exoskeleton Devices, Gait Rehabilitation, Mobility

## Project Definition

Within the increasing elderly and stroke survivor populations each year, impaired human gait is the most affected disorder. According to an estimate given by the National Institute of Neurological Disorders and Stroke (NINDS), in USA there are more than 795,000 strokes cases every year [1]. Stroke is the fourth leading cause of death in the country and causes more serious long-term disabilities than any other disease. Nearly three-quarters of all strokes occur in people over the age of 65 and the risk of having a stroke more than doubles each decade after the age of 55. For the gait rehabilitation, the effectiveness of conventional treatments and devices (e.g., treadmill) requires further assessment and improvement.

Our major goal is to investigate prototype devices that will increase mobility, independence, and quality of life of elderly fall-prone individuals and stroke survivors with balance impairments. As a means towards satisfying this goal, students at the University of the District of Columbia (UDC) previously developed a Portable Harness Ambulatory System (PHAS) prototype. Here we discuss design enhancements that will improve ease-of-use to the end-users. A major design enhancement to the PHAS is to make the PHAS prototype autonomous by integrating the sensors and electric hub wheels. Furthermore, we propose the addition of a compact, lower limb exoskeleton prototype device as an accessory to increase PHAS capacity towards severe neurological or musculoskeletal injuries. Through clinical research studies carried out in the last two decades, gait rehabilitation using robotic devices (e.g., exoskeletons) with harness ambulatory devices were effective but still required further investigation [2, 3, 4]. Our goal is to develop the lower limb exoskeleton to assist to severely immobile patients to aid walking while using the PHAS (to prevent and safeguard from falls) [5].

We aimed to address the above via faculty collaborations and multidisciplinary Senior Capstone Project(s), involving 3 Electrical & Computer Engineering (ECE) and 3 Mechanical Engineering (ME) students and guidance from their faculty advisors in ME and ECE. The merit of the proposed investigation is devices that may aid those suffering from moderate to severe (balance) mobility. Impacts on the students are that, through these investigations and projects, experiential learning will provide them with integrating concepts learned in the classroom with real world problems.

## Background: Gait Rehabilitation Devices

Rehabilitation aims to help improve patients' functionality, while taking into account their disabilities and personal needs. Restoration, or improvement, of an individual's balance (i.e., standing and/or walking) ability is a hallmark of a (gait) rehabilitation program. In recent years, it has been well established that task-specific training is needed for function restoration (e.g., for balance and posture). The most widely adopted approaches for neurological rehabilitation of walking include: 1) *conventional gait rehabilitation* [7, 8]; 2) *bodyweight support rehabilitation* [9]; and 3) *robot- assisted gait rehabilitation* [10]. Depending on the patient's physical condition, *conventional gait training* (Figure 1) takes place with assistance provided by therapists. This makes it labor intensive for, and can also cause injury to, the physiotherapists who are providing manual assistance for control of the trunk, pelvis, hip, knee, and ankle simultaneously, as well as lifting/ supporting the patient as needed.)

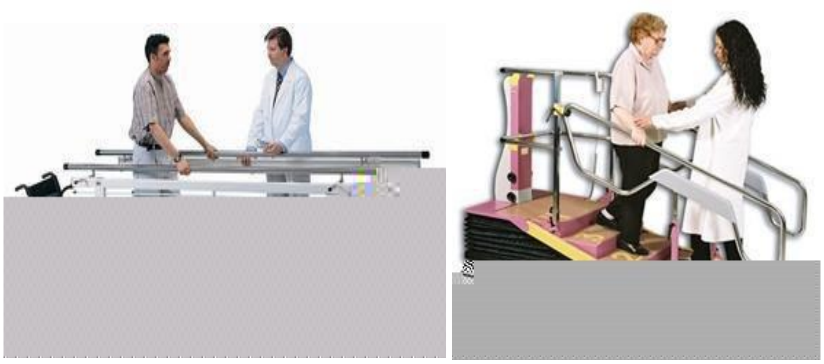


**Figure 1: Conventional gait training** [7, 8]

In order to reduce the risk of falling for those who cannot keep balance, *body weight support* (BWS) has been used to assist gait training. Using an overhead harness, BWS unloads a proportion of body weight to assist patients in an upright position.

**Figure 2: Partial Body Weight Support Gait Rehabilitation [9]**

BWS (Figure 2) is sometimes used during walking overground. However, those who have weak muscles in the lower limbs cannot create enough friction for forward progression if too much of their weight is supported. Furthermore, rehabilitation of walking with BWS is usually carried out using a treadmill.

*Robotics gait rehabilitation* (Figure 3) utilizes mechanical actuation to induce motion of the human body. Mechanically actuated orthoses can provide consistent, repetitive and prolonged gait training. Such systems include the Lower Extremity Powered Exoskeleton (LOPES), the Active Leg Exoskeleton (ALEX), the Ambulation-assisting Robotic Tool for Human Rehabilitation (ARTHuR) the Pelvic Assist Manipulator and the Pneumatically Operated Gait Orthosis (PAM/POGO), and 3 commercially available rehabilitation devices: Lokomat, Loko-help and the G-EO robotic gait system [10]. All are expensive, require expert assistance and are complex to install. However, they can be found in clinics and individuals using them require constant monitoring by the physician.

**Figure 3: Robot assisted gait rehabilitation**

A relatively new device that uses BWS for physical therapy and exercise training for patients with neurological or musculoskeletal injuries, diseases, or muscle weakness is the NaviGAITor system (Figure 4) (developed jointly by the University of Hartford and the Albert Einstein College of Medicine/Montefiore Medical Center in New York City [11]). This device enables exercise and movement training in all three planes of motion without risk of falls and injuries and system operation can be directed manually or automatically. The system consists of an overhead crane that can move along 3 axes (e.g., “X”, “Y”, in the (earth) horizontal planes, and “Z”, in the (earth) vertical plane). Motion is motorized and it is monitored by a control system that uses LabVIEW as its graphical user interface (or GUI). The X and Y motions of the system are controlled by monitoring the cable position’s angular displacement. This cable displacement angle is read by LabView and allows the patient to either start or stop walking with minimal effort. The Z-axis has its own very similar control system however it uses a self-locking vertical displacement monitoring system that monitors the force and acceleration profiles of the cable. If the patient falls, the cable force increases and the system locks the cable immediately to catch the patient. The patient is then able to re-establish his or herself.

**Figure 4: NaviGATOR**

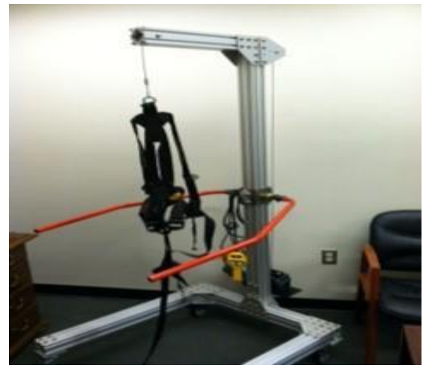


**Figure 5: Portable Harness Ambulatory System**

Although the above devices can be utilized in clinics and rehabilitation centers, setbacks are the following: 1) rehabilitation is dependent on patient's limited musculoskeletal abilities and not all patients will be benefit from these devices; 2) rehabilitation is sometimes limited to treadmill walking, which differs from "natural" walking; 3) rehabilitation equipment is available in select hospitals or physical therapy clinics and home installation is rather complex and highly expensive; 4) professional assistance is required while using these devices; 5) commercial exoskeletons are available in but they are prohibitively expensive.

*Portable Harness Ambulatory System (PHAS):* A Portable Harness Ambulatory System (or "PHAS") was designed by senior ME students at the University of the District of Columbia (UDC) as a part of senior capstone project (Figure 5) [12] (Demisse, Emmett and Hailemeskel). The Senior Capstone Design Project was a combined effort of ECE and ME students and the prototype's main purpose was to aid rehabilitation therapy for fall-prone elderly and stroke survivors while in their home environment.

For the *PHAS*, the improvements need to be made on the current prototype, such as: 1) lightweight and compact with adjustable height; 2) incorporation of a brushless DC (BLDC) motor to sense motion intent; 3) incorporation of feedback from physical therapists; 4) safe and easy to use while in the home environment. Below we describe the incorporation of a BLDC motor. However, future work will include feedback from physical therapists and end-users patients.

*Control System for the Brushless DC Motor:* During pilot testing on 5 normal, < 28 year old individuals, the wheels for the PHAS were providing some resistance, and therefore required pulling by the individual to use the device and thus slower gait speed. This being the case, a motor needed to be implemented such that when the individual's intent to move was sensed, the wheels would also move (Figure 6). A motor controller determines the start and stop of the motor, selects forward or reverse rotation, selects and regulates the speed, regulates the torque and also monitors the overloads. The KU63 [16, 17] motor controller is used in this design because it is small and lightweight and well suited for 250 W motors. Brushless DC electric motor (BLDC motors, BL motors), also known as electronically commutated motors, are synchronous motors that are driven by a DC-to- AC power inverters controlled with a dedicated Motor Controller (MC), in this case the KU 63 motor controller. In this context, the AC electric signals produced, do not imply a sinusoidal waveform, but rather a bi-directional current with no restriction on waveform. Additional sensors and electronics control the inverter output amplitude and waveform (and therefore the percent of DC bus usage/efficiency) & frequency (i.e., rotor speed).

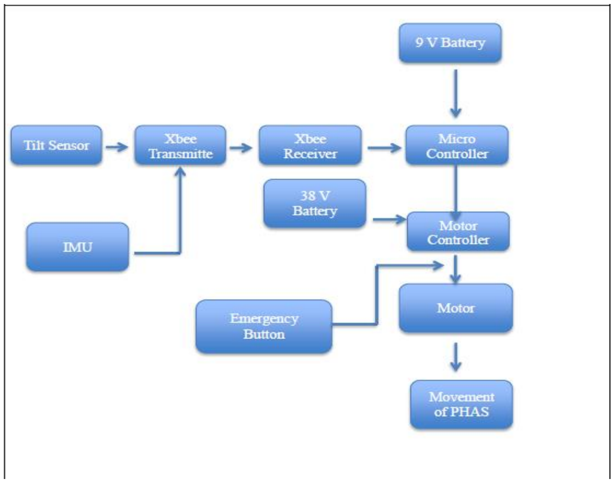



**Figure 6: Block Diagram for control of PHAS**

Figure 6 shows the block diagram of the PHAS Control system. A Tilt sensor and an Initial Measurement Unit (IMU) sensor are attached to the PHAS. The sensors data are transmitted using Xbee transmitter/receiver modules in a point-to-point connection to a hub Microcontroller (the Arduino UNO). The Arduino micro-controller contains fourteen digital I/O pins and six analog inputs. It converts the user inputs, interprets them and outputs a PWM to the motor for speed control. The motor used is the 3 phase, 4 pole, 250W BLDC motor.

The rotor of a brushless motor is often a permanent synchronous motor but can also be switch reluctance motor or induction motor. Connecting a DC voltage across a set of stator coils in a BLDC motor generates a magnetic field. The interaction of the permanent magnet rotor with the magnetic field causes the motor to turn. Sequentially connecting the DC voltage across the next set of stator coils rotates the orientation of the magnetic field that causes the rotor to revolve. To maintain synchronization with the rotating stator magnetic field, the rotor position must be known at fixed angular intervals. The 3-phase brushless DC motor is controlled using the generated waves from the KU63 motor controller, with integrated Hall sensors that are used for rotor position detection. The Arduino microcontroller was powered by 9 V batteries. The motor controller was powered by 39 V DC batteries. The motor controller controls the motor and the microcontroller was used to control the speed of the motor. As a result with a desired speed, the PHAS can be moved. Figure 7 shows the control system circuit connection.

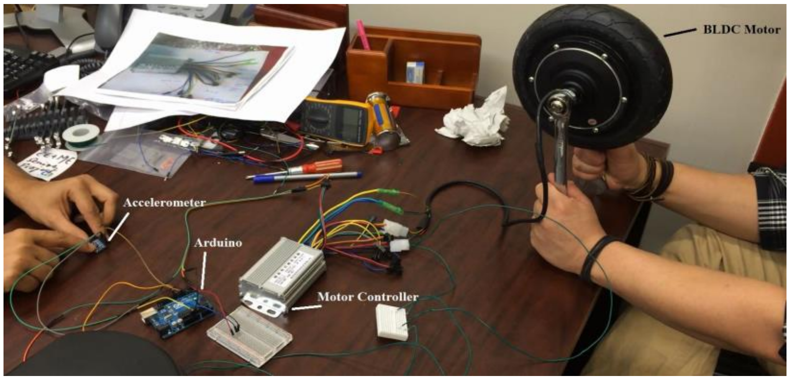



**Figure 7: Connection of Arduino, Accelerometer, Motor Controller and BLDC Motor**

## Mechanical Design of Lower Limb Exoskeleton System

### *Gait Cycle*

The human gait cycle is divided into stance and swing phase. Swing phase can be further divided into two phases: swing-flexion and swing- extension as shown is Figure 8 [6].

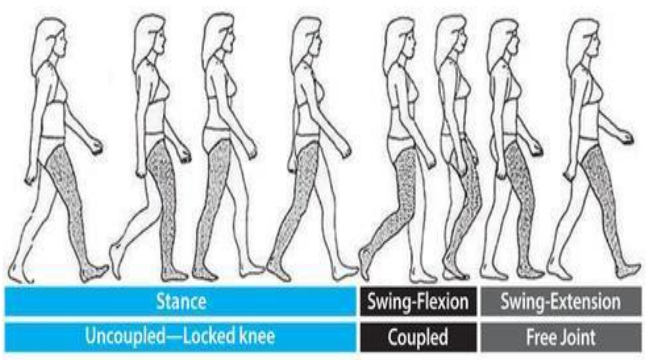



**Figure 8: Three- phase walking cycle and the corresponding coupling stages [6]**

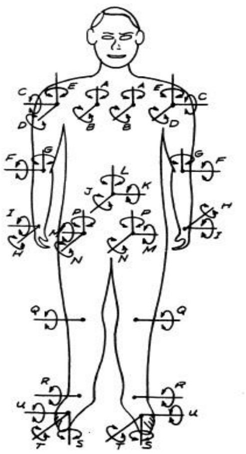
**Phase I: Stance:** During the stance, the person's foot is in contact with the ground and the leg is bearing weight. The hip goes through extension while the knee stays locked.

**Phase II: Swing-flexion:** At maximum hip extension, swing-flexion phase begins in which both the knee and hip flexes to achieve toe clearance.

**Phase III: Swing-extension:** At maximum knee flexion, swing-extension phase begins and the knee re-extends to prepare for heel strike.

The main aim was to design the lower limb exoskeleton system that can be integrated to the existing PHAS unit, and for the PHAS unit to be equipped with wheels and tilt sensors needed to sense and approximate the human gait cycle (Figure 8).

For the *lower limb exoskeleton*, the design requirements are the following: 1) lightweight, compact, and wearable; 2) must simulate human leg motion; 3) must not be difficult to move or conflict with other body motions; 4) safe and easy to use while in the home environment. We consider designing the lower limb exoskeleton with degrees of freedom on hip, knee and ankle joints. Initially, we attempted to develop the prototype that could be controlled with the PHAS unit.



*Hip Joints:* The hip joint is capable of the following movements: flexion, extension and hyperextension (Figure 9, movement M), adduction and abduction (Figure 9, movement N), inward and outward rotation (Figure 9, movement P).

*Knee Joints:* Flexion and extension of the knee (Figure 9, axis Q) are permitted in the exoskeleton by an axis of rotation passing through the knee (Figure 9, axis Q**).**

*Ankle Joint:* Dorsal and plantar flexion of the ankle (Figure 9, axis R) is permitted in the exoskeleton by an axis of rotation passing through the ankle joints.

**Figure 9: Degree of freedom on joints of human body**

To provide the rotation about an axis on each joint, ball bearing that reduces the friction between the joints is used to obtain the desired angle of rotation. Using anthropometric data for the human lower body (Table 2 & Figure 10), we were able to determine dimensions for our design.

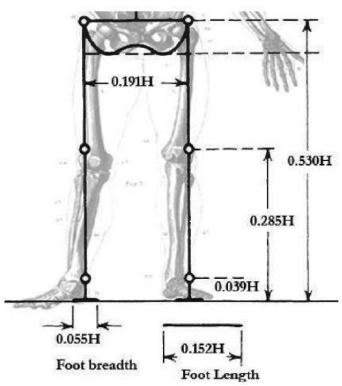



**Table 2: The Anthropometric Parameters of the Human Segments [19]**

| Measure | Thigh | Shank | Foot |
|---|---|---|---|
| Mass | $m_1 = 0.1*m$ | $m_2 = 0.0465*m$ | $m_3 = 0.0145*m$ |
| Moment of Inertia | $I_1 = m_1*(0.323*L_1)$^2 | $I_2 = m_2*(0.302*L_2)$^2 | $I_3 = m_3*(0.475*L_3)$^2 |
| Centre of Mass | $L_{c1} = 0.433*L_1$ | $L_{c2} = 0.433*L_2$ | $L_{c3} = 0.5*L_3$ |
| | From hip | From knee | From ankle |

**Figure 10: Measurements for Human Lower Body [18]**

Considering the anthropometric data and parameters for the human lower body, the 3- D computer-aided design (CAD) model is created using the CREO software (Figures 11 through 14).

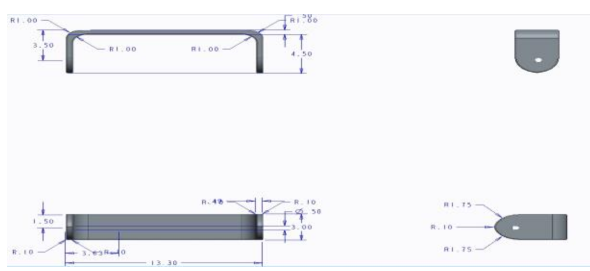


**Figure 11: CAD model of hip support and back frame**

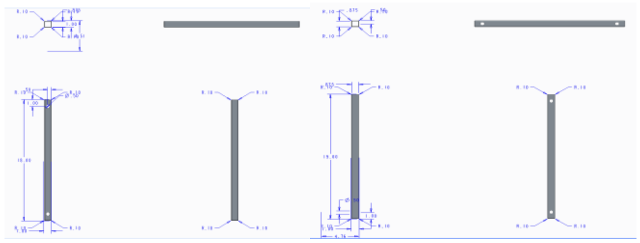


**Figure 12: CAD model of shanks (left) and thigh (right)**

The foot is capable of adduction - abduction (Figure 9, movement S), inversion - eversion (Figure 9, movement T) and flexion – hyperextension (Figure 9, movement U). Adduction and abduction are permitted in the exoskeleton by an axis of rotation perpendicular to the ground and located behind and outward from the leg (Figure 9, axis S). This axis is not located at the approximate center of rotation. However, the range of movement is small (10 deg. total motion); thus the relative motion between the wearer and the exoskeleton will be small. Inversion and eversion are permitted in the exoskeleton by a pinned joint located behind the foot of the wearer, with the axis of rotation passing through the joint between the ankle and the foot (Figure 9, axis T). Flexion and hyperextension are permitted in the exoskeleton by a separation in the footplate (Figure 9, axis U). Both sections of the footplate are attached to the wearer's shoe. The separation permits the shoe to flex, and thus permits flexion and hyperextension of the foot. A drawing of the exoskeleton joint for the foot and ankle joint is shown in Figure 13.

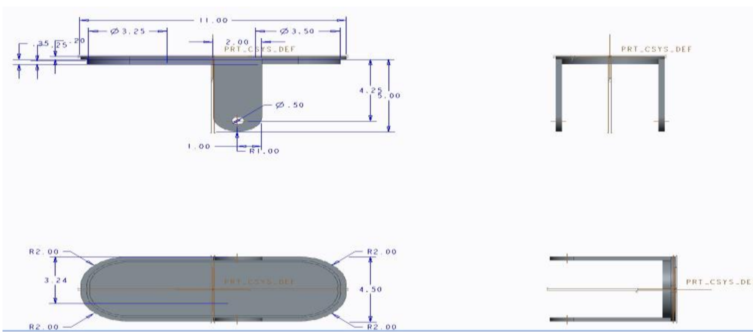


**Figure 13: CAD model of foot**

**Figure 14: Assembly of parts**

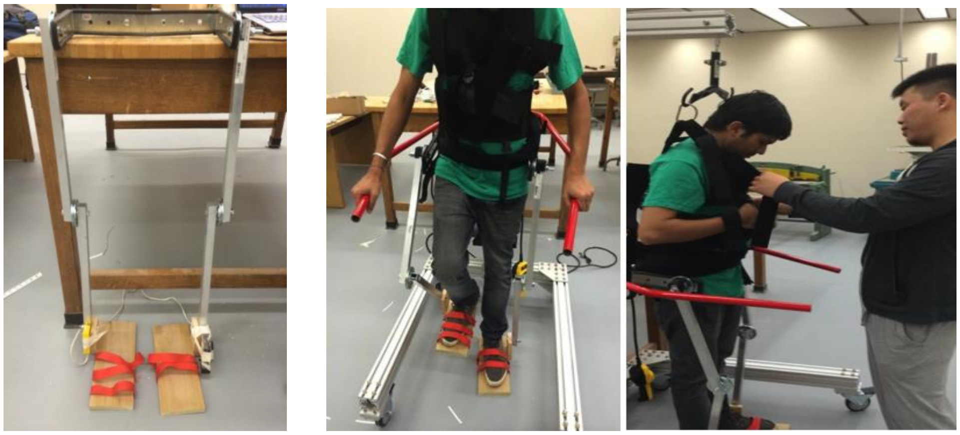
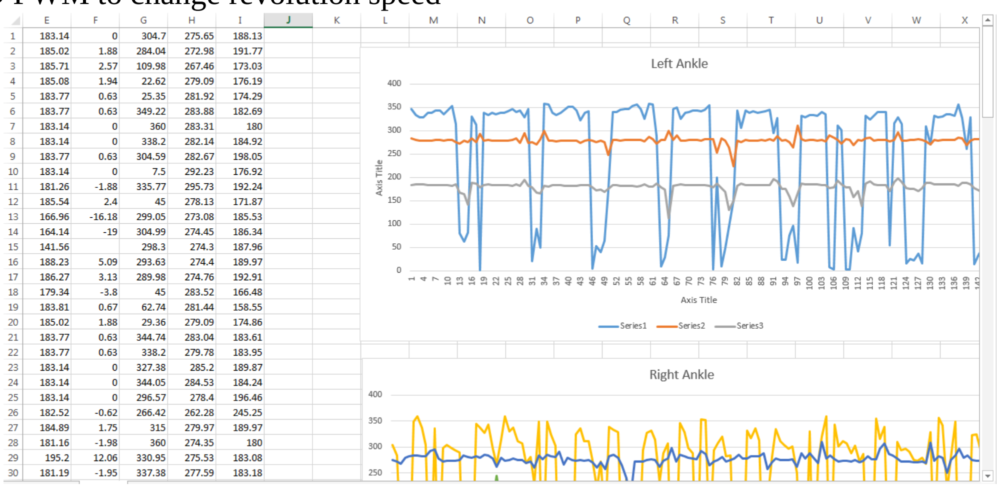


**Figure 15: Lower Limb Exoskeleton Prototype (left) and Exoskeleton being used with the PHAS (right)**

Prior to construction, stress analysis simulations (not shown) were conducted on all parts. Figure 15 displays the lower limb exoskeleton prototype made predominantly of aluminum (left) and the prototype exoskeleton being used in conjunction with the PHAS (right). For proof of concept, we sampled accelerometer data and Left ankle range of motion are captured and recorded in Figures 16. However, we plan on doing further characterization in the future. The following operations were implemented for the PHAS motor control:

- RESET switch to reboot the system
- START/STOP switch to start and stop motor revolution
- FORWARD and REVERSE to change revolution direction
- SPEED PWM to change revolution speed



| | E | F | G | H | I |
|---|---|---|---|---|---|
| 1 | 183.14 | 0 | 304.7 | 275.65 | 188.13 |
| 2 | 185.02 | 1.88 | 284.04 | 272.98 | 191.77 |
| 3 | 185.71 | 2.57 | 109.98 | 267.46 | 173.03 |
| 4 | 185.08 | 1.94 | 22.62 | 279.09 | 176.19 |
| 5 | 183.77 | 0.63 | 25.35 | 281.92 | 174.29 |
| 6 | 183.77 | 0.63 | 349.22 | 283.88 | 182.69 |
| 7 | 183.14 | 0 | 360 | 283.31 | 180 |
| 8 | 183.14 | 0 | 338.2 | 282.14 | 184.92 |
| 9 | 183.77 | 0.63 | 304.59 | 282.67 | 198.05 |
| 10 | 183.14 | 0 | 7.5 | 292.23 | 176.92 |
| 11 | 181.26 | -1.88 | 335.77 | 295.73 | 192.24 |
| 12 | 185.54 | 2.4 | 45 | 278.13 | 171.87 |
| 13 | 166.96 | -16.18 | 299.05 | 273.08 | 185.53 |
| 14 | 164.14 | -19 | 304.99 | 274.45 | 186.34 |
| 15 | 141.56 | | 298.3 | 274.3 | 187.96 |
| 16 | 188.23 | 5.09 | 293.63 | 274.4 | 189.97 |
| 17 | 186.27 | 3.13 | 289.98 | 274.76 | 192.91 |
| 18 | 179.34 | -3.8 | 45 | 283.52 | 166.48 |
| 19 | 183.81 | 0.67 | 62.74 | 281.44 | 158.55 |
| 20 | 185.02 | 1.88 | 29.36 | 279.09 | 174.86 |
| 21 | 183.77 | 0.63 | 344.74 | 283.04 | 183.61 |
| 22 | 183.77 | 0.63 | 338.2 | 279.78 | 183.95 |
| 23 | 183.14 | 0 | 327.38 | 285.2 | 189.87 |
| 24 | 183.14 | 0 | 344.05 | 284.53 | 184.24 |
| 25 | 183.14 | 0 | 296.57 | 278.4 | 196.46 |
| 26 | 182.52 | -0.62 | 266.42 | 262.28 | 245.25 |
| 27 | 184.89 | 1.75 | 315 | 279.97 | 189.97 |
| 28 | 181.16 | -1.98 | 360 | 274.35 | 180 |
| 29 | 195.2 | 12.06 | 330.95 | 275.53 | 183.08 |
| 30 | 181.19 | -1.95 | 337.38 | 277.59 | 183.18 |



**Figure 16: Raw Data recorded using accelerometer on Lower Limb Exoskeleton**

## Conclusion

Here we describe a prototype lower limb exoskeleton device has been designed in conjunction with the PHAS. These devices will pave a new way for further research on human gait and rehabilitation, as well as home-based rehabilitation. The system has been designed to be useful for rehabilitation of stroke survivors, neurological disorder patients and musculoskeletal disorder patients, but still needs to be evaluated on the end-user. We aim to continue the above work via faculty collaborations and multidisciplinary Senior Capstone Project(s), involving 3 Biomedical Engineering, 3 Electrical & Computer Engineering, and 3 Mechanical Engineering students and guidance from their faculty advisors in BME, ME and ECE, as well as integration of feedback from physical therapists and patients.

## References

1. NINDS, “Post-stroke rehabilitation fact sheet,” *Publihsed report National Institute of Neurological Disorders and Stroke*, vol. 07, no. 4846, 2007.
2. S. Hesse, H. Schmidt, and C. Werner, “Machines to support motor rehabilitation after stroke: 10 years of experience in berlin,” *Journal of Rehabilitation Research and Development*, vol. 43, no. 5, pp. 671–679, 2006.
3. L. E. Kahn, P. S. Lum, W. Z. Rymer, and D. J. Reinkensmeyer, “Robot-assisted movement training for the stroke-impaired arm: Does it matter what the robot does?,” *Journal of Rehabilitation Research and Development, vol. 43, no. 5, pp. 619–630*, 2006.
4. D. Shetty, A. Fast, C. Campana, and M. L., “Mechatronic integration in the design of ambulatory rehabilitation device,” Proceedings of the ASME International Mechanical Engineering Congress Exposition Canada, 2010, pp. 209–216.
5. S. Banala, S. H. Kim, S. Agrawal, and J. Scholz, “Robot assisted gait training with active leg exoskeleton (alex),” Neural Systems and Rehabilitation Engineering, IEEE Transactions on, vol. 17, no. 1, pp. 2–8, 2009.
6. P. Stegall, K. Winfree, D. Zanotto, and S. Agrawal, “Rehabilitation exoskeleton design: Exploring the effect of the anterior lunge degree of freedom,” Robotics, IEEE Transactions on, vol. 29, no. 4, pp. 838–846, 2013.
7. T.H. Baluch, A. Masood, J. Iqbal, U. Izhar and U. S. Khan, “ Kinematic and Dynamic Analysis of a Lower Limb Exoskeleton”, World Academy of Science, Engineering and Technology, 69,2012.
8. M. Wirz, “Ambulatory rehabilitation in patients with spinal cord injury, A clinical perspective”, University of Maastricht, Netherlands, 2013.
9. M. Cenciarini and A. M. Dollar, “Biomechanical Considerations in the Design of Lower Limb Exoskeletons”, IEEE International Conference on Rehabilitation Robotics, Switzerland, 2011.
10. N.J. Mizen, “Preliminary Design of a Full-scale, Wearable, Exoskeleton Structure”, Cornell Aeronautical Laboratory, Inc., Buffalo, New York, 1978.
11. S.M. Nancy, S.S. Hassan and M.Y. Hanna, “A Modified Dynamic Model of the Human Lower Limb During Complete Gait Cycle”, International Journal of Mechanical Engineering and Robotics Research, vol. 2, No. 2, April 2013.
12. D. Shetty, N. Kumar, P. Moussavoub, and N. Poudel, “Mechatronic Integration for Portable Harness Ambulatory System for Rehabilitation of gait Disorders of Elderly and Stroke Survivors”, Biomedical Instrumentation Unit, CSIR-CSIO, Chandigarh India School of Engineering & Applied Sciences, UDC, Washington DC USA.
13. S. Demisse, T. Emmett, B. Hailemeskel, P. Moussavou and M. Regassa, “ Portable Harness Ambulatory System”, Senior Design Report, University of the District of Columbia, Washington D.C., 2012.
14. J.L. Pons, J.C. Moreno, F.J. Brunetti, E. Rocon, “Lower-Limb Wearable Exoskeleton” From Wearable Robots: Biomechatronic Exoskeletons by Jose L Pons, Wiley Online Library, March 2008.
15. S. Chowdhury and Neelesh Kumar, “Estimation of Forces and Moments of Lower Limb Joints from Kinematics Data and Inertial Properties of the Body by Using Inverse Dynamics Technique ”. Journal of Rehabilitation Robotics, 2013, 1, pp. 93-98.
16. KU63 Motor Controller, http://www.avdweb.nl/solar-bike/electronics/ku63-motor-controller.html. Analog Devices, Measurement Techniques for Industrial Motion Control (MS-2652 Technical Article), PWM Speed Control.
17. 3-Phase Brushless DC Motor Control 120-Degree Trapezoidal Drive with Hall Sensors for MC-LVKIT-714 Motor Control Evaluation System, © NEC Electronics Corporation, 2006, Document No. U18028EU1V1UME0. NEC Electronics America, Inc., 2880 Scott Blvd, Santa Clara, CA 95050-2554.
18. Herman, Irving P. *Physics of the human body*. Springer Science & Business Media, 2007.
19. Clauser, Charles E., John T. McConville, and John W. Young. *Weight, volume, and center of mass of segments of the human body*. ANTIOCH COLL YELLOW SPRINGS OH, 1969.

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# Selective Forwarding Attacks Detection in WSNs

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## Abstract

Wireless sensor networks (WSNs) are susceptible to the most security attacks. Limited capacity of sensor nodes accounts for the security attacks on WSNs. Applications such as military surveillance, traffic surveillance, healthcare, and environmental monitoring are impacted by security attacks. Hence, researchers have created various types of detection approaches against such attacks. There are also some limitations such as reliability, energy efficiency, and scalability, which affect sensor nodes. These limitations mostly affect the security of WSNs. Selective forwarding attack is an example of an attack that is not easily detected particularly in the networks layer. In this type of attack, malicious nodes function in the same way as other nodes in the networks. However, it tries to drops the sensitive packets prior to transferring the packet to other sensor node. In this paper, we propose an approach that protects data from selective forwarding attacks. The approach keeps the data transmission moving safely between sensor nodes and at the same time detects malicious nodes.

## Keywords

Wireless Sensor Networks (WSNs) and Selective Forwarding Attacks.

## Introduction

Wireless sensor networks contain numerous sensors. These sensors communicate with huge numbers of small nodes by using radio links. Sensor networks consist of the source and base station. A sensor is composed of four basic units, which are sensing unit, processing, transceiver, and power[1]. The task of sensor nodes is collecting the information that is needed by smart environments. These environments are for instance: home, transportation system, military, healthcare, buildings etc. The study of the Wireless Sensor Network is crucial in computer science and engineering and has an impact on the community, in economic, and industrialization. Nowadays, many distributed sensor networks can be deployed and have a self-organizing ability. Computational ability needs the sensor nodes, which are not overloaded with too many complicated functions.

WSNs work in open networks with the limited resources of nodes and obstacles. Thus, they are prone to many types of attacks. The security of WSNs has been studied over the past few years. The most traditional threats include eavesdropping, nodes being compromised, interruptions, modified or injected malicious packets, compromised privacy and the denial of service attacks[2]. Networks have different applications that comprise of several levels of monitoring, tracking, and controlling. Therefore, applications are employed for specific purposes. In military applications, sensor nodes include monitoring, battlefield surveillance, and object tracking. The battlefield monitors utilized in military operations have prompted the development of WSNs. In medical applications, sensors assist in patient diagnosis and monitoring. Applications are deployed to monitor an area and then react when a sensitive factor is recorded[3]. There are also some potential applications such as environmental monitoring, factory instrumentation and inventory tracking.

## Selective Forwarding Attack

There are several types of attacks that exist in WSNs. Most security attacks are located in the network layer. Furthermore, a sensor node may derive benefits from multi-hop by simply refusing to route packets. It can be performed frequently with the net result. Malicious nodes will not be incapable to change or modify the message if the neighboring node marks a route[4]. The Network layer receives varieties of attacks. For example, injecting the path between sensor nodes.

Selective forwarding attack is one of the insider attacks. A more subtle form of this attack is when an adversary selectively forwards packets. The adversaries are able to create routing loops that attract or repel network traffic. They also can be extend or shorten source routers, generate false messages, and attempt to drop the sensitive information. The selective forwarding attack is not easy to detect particularly when compromised nodes drop packets selectively. The dropped packets come from one node or a set of nodes. A malicious node can refuse to forward the messages or drop packets randomly. For this reason, the base station may not receive the entire message[5, 6].

## Related Works

Yu and Xiao[6] proposed an approach based on lightweight security to detect a selective forwarding attack in the environment of sensor networks. The approach utilized a multi-hop acknowledgment to launch alarms by obtaining responses from the nodes that are located in the middle of paths. Authors assumed the approach could identify malicious sensor nodes. The aim of the detection attack is to send an alarm when a malicious node is discovered, which indicates a selective forwarding attack. The authors noted that the detection accuracy of their approach exceeds 95% with an error rate of 15%. Yu and Xiao employed two detection processes in the scheme: a downstream process (the direction on the way to the base station) and an upstream process (the direction on the way to the source node). In the upstream process, a report packet is created and sent to the base station hop by hop when nodes detect a malicious node. Therefore, the base station would receive the alarm packet and forward multiple hops that are produced by the node. An acknowledgement packet and an alert packet will drain the energy during detection.

The identification of suspect nodes is reported via an intermediate node. First, Xiao, Yu, and Gao[7] proposed a checkpoint-based method. In this approach, a node is randomly selected as the checkpoint to send an acknowledgement message for detecting the adversary. It is a mechanism used to identify suspect nodes in a selective forwarding attack. They have attempted to improve the technique by detecting an abnormal packet in sensor networks. They assumed that any compromised nodes could not create alert packets with the aim of maliciously prosecuting other nodes. After collecting evidence to determine whether the node is a malicious node, the source nodes determine the position of the suspect node according to the location. However, it is no guarantee for reliable transmission of messages even though the adversary is positioned by acknowledgement.

Tran Hoang and Eui-Nam[8] proposed an approach against selective forwarding attacks that consists of a lightweight detection mechanism. The detection is a centralized cluster, which utilized the two-hop neighborhood node information and overhearing technique. It is dependent on the broadcast nature of sensor communication and the high density of sensors. Each sensor node is provided with a detection module that is constructed on an application layer. Sensor node sets routing rules and two-hop neighbor knowledge to generate an alert packet. Hoang and Nam suggested that the two routing rules make the monitoring system more suitable. Thus, the first rule is to determine if the destination node forwards the packet along the path to the sink. It generates an alert packet with the malicious factor $\alpha$ to the sender/source node. The second rule governs that the monitor node waits and detects the packet that was already forwarded along the path to the sink. It verifies the two-hop neighbor knowledge to assess whether the destination node is on the right path to the sink. If not, it generates an alert packet with the malicious factor $\beta$ to the sender/source node.

## Proposed System

In wireless sensor networks, several nodes transfer sensor readings to the base station in order to process data. Military bases are important in using sensor networks to explore enemy forces. Sensor nodes have limited sensing and computation. There is also communication ability. Sensors gather data when they detect abnormal movement of enemy forces such as warplanes, war tanks movement in battlefields etc. Data transmission is sent to the base station using routers. So, the attacker compromises nodes to attack the networks (Figure 1). Malicious nodes reject to send the entire message. Thus, it drops the important information and keeps the remaining message to forward to the next node. Because the military applications have sensitive information, selective forwarding attacks damage the transmission message between the source and base station as well as between sensor nodes.

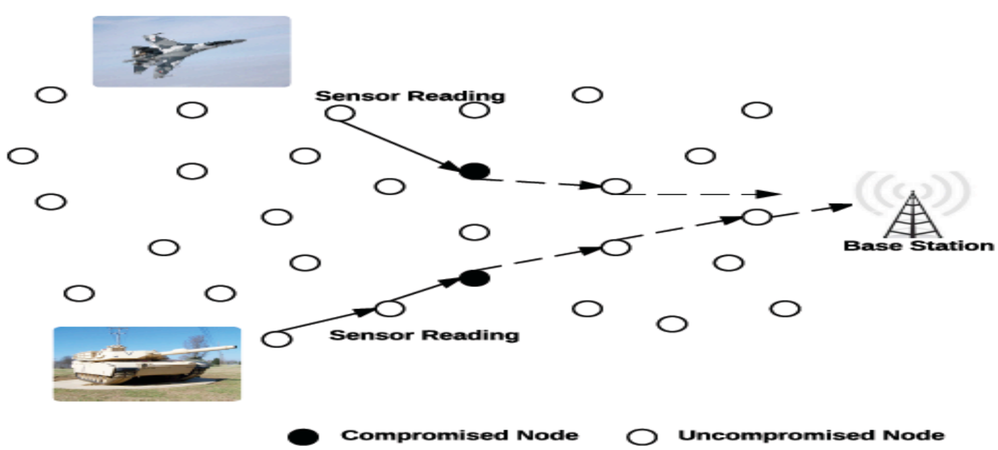


Figure 1. Sensor nodes during selective forwarding attacks

In networks, the malicious node tries to create obstacles during the transfer of packets in the networks. These obstacles include forwarding certain messages to different paths, generating an inaccurate route in the network and also, attempting to delay the transfer of packets between nodes. Therefore, selective forwarding detection approach locates a secure route during data transmission. In this section, we introduce our assumptions and detection approach. Sensor networks are susceptible to several types of attacks.

WSNs is composed of base station and sensor nodes. Sensor nodes are grouped into clusters. Each cluster has several nodes as shown in Figure 2. A packet is transferred via a source node to the base station using a route. During the transmission any malicious node drop a packet, the neighbor nodes work as monitoring and detect the packet that drop by the adversary. In our approach, any node located in an intermediate is responsible to detect the malicious nodes.

The selective forwarding attack in example of Figure 3 may happen between sensor nodes. Thus, node “A” transfers the packets to node “B” and then node “B” stops forwarding the packets to node “C”. As a result, node “B” may forward packets to malicious node. Therefore, packets will not arrive to the base station.

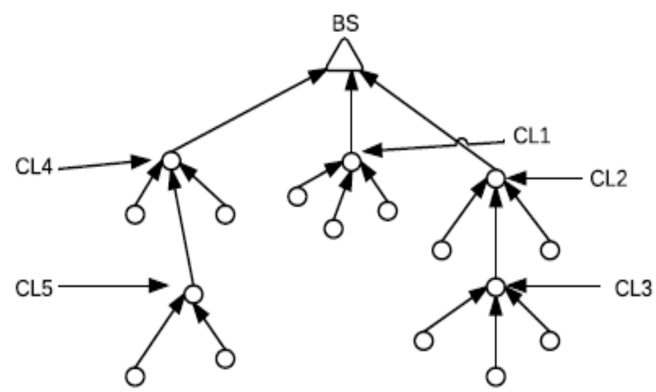


Figure 2. Nodes are arranged in Clusters

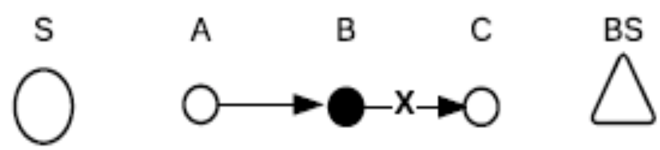


Figure 3. Example of Selective Forwarding Attack

### A. Assumptions

The network layer in WSNs is threatened by some attacks such as wormhole, sinkhole, and many types of attacks. Wireless sensor networks are very difficult for the transmission. In order to construct a simple solution to detect the selective forwarding attack, we make assumptions for our approach detection that are suitable in the sensor networks. These assumptions are as follow:

- Secure communication should be part of the networks.
- Malicious nodes should not drop any packet prior to launch the selective forwarding attack.
- The adversary cannot compromise a sensor node during the deployment.
- The authentication broadcast protocols implemented for each sensor node.

## B. Analysis

Though the network layer in WSNs is threatened by many security attacks, this paper only focuses on the selective forwarding attack. There are some disadvantages of selective forwarding attacks for instance, malicious nodes may refuse to forward certain messages or sensitive information and drop them, and the adversary overhearing movement between nodes might be capable to simulate selective forwarding by jamming. Consequently, we design a multi layers approach, which includes three security layers. The first layer is data receiving. In this layer, the important information is filtered and stored. The information includes message fields that are beneficial on the rules processing. The second layer is rules processing. In this section, rules must be applied to the stored data before the sensor nodes deployed. The message can be rejected or refused. In addition, no rules will be applied to the message since it fails. The third layer is detection. The selective forwarding detection approach involves identifying the malicious nodes and chooses a secure route to transfer data between the source and base station. Furthermore, the multi layer approach considers reliability, energy efficiency, and scalability. It assumes that detection accuracy is high even when the radio condition is poor.

## C. Simulation

In this section, we used NS2 simulation to estimate the performance of the multi-layer detection approach. We have focused our simulation on malicious detection rate and packet delivery ratio. In our simulation, 200 sensor nodes are deployed in an area network size 500 * 500 square meters. Hence, each node has a 35 meters transmission range and sensing range of node is 30 meters. Consequently, the communication overheads are decreased.

Figure 4 shows the performance of our approach for the packet delivery ratio. Thus, the malicious nodes are appearing. During the increasing malicious nodes drop packet, our approach can achieve packet delivery ratio under the overflow of attack. Therefore, it can be accomplished up to 40% malicious nodes. The packet delivery ratio is decreased rapidly while the malicious nodes increase. The effect of the malicious increase of packet delivery ratio, it takes time to defeat and take them away.

The approach in Figure 5 is a perfect detection rate. It is more than 98% as long as the noise error is 2-4%, and the malicious nodes are under 12%. In fact, the noise error rate increases while the detection of malicious nodes failed. Losing packet happened when the collision ratio and malicious nodes increased. Sometime the radio condition is poor because the communication in WSNs. As a result, the detection rate of the malicious nodes will be impacted. We observe that our approach is more efficient when the number of detection nodes increased. The probability of missed detection occurs when collision is available in the network at the time by monitoring the node attempting to send an alert packet.

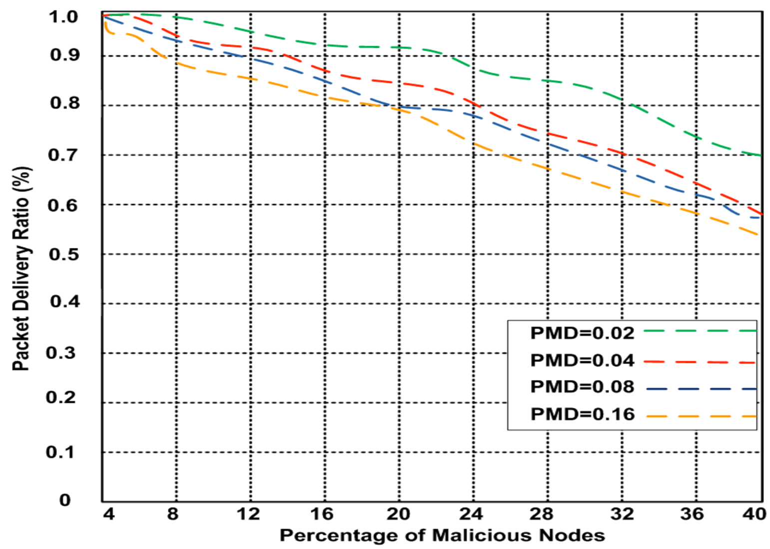


Figure 4. Packet delivery ratio under malicious attacks in WSN

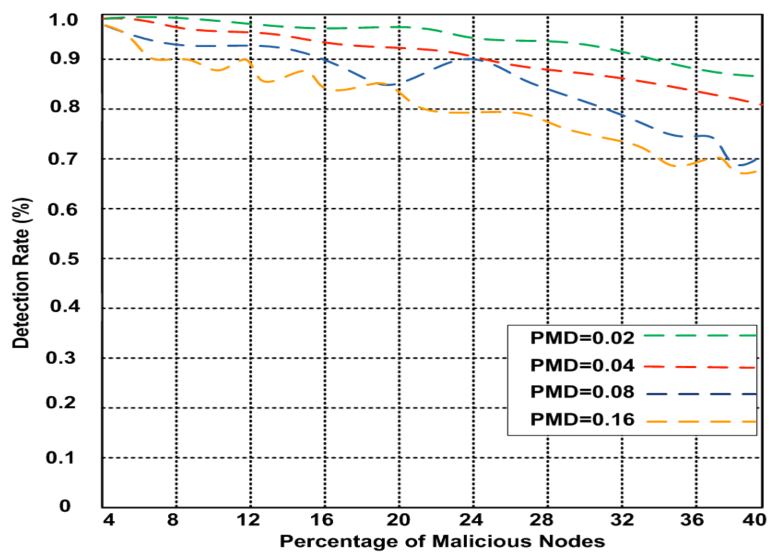


Figure 5. Detection of malicious nodes in the WSN

## Conclusion

The security of WSNs has become increasingly concerning. The use of wireless sensor networks is progressively employed in environmental, commercial, health and military applications. The security of packets and the transmission period is fundamentally necessary in WSNs. The selective forwarding attack poses severe threats to wireless networks. In this paper, we propose an approach in detecting this type of attack in WSNs. Monitor sensor nodes detect selective forwarding attacks using neighbor nodes. Our approach is an efficient way of detecting the attacks. We also take into consideration reliability, energy efficiency, and scalability. Analysis and simulation show that our approach is more effective when the numbers of detection nodes increased.

## References


[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "Wirelss sensor networks: A survey," Computer Networks, 38(4):393-422, 2002.

[2] A. Perrig, J. Stankovic, and D. Wagner, "Security in Wireless Sensor Networks", Communications of the ACM, 47(6):53– 57, June 2004.

[3] David Martins, and Herve Guyennet, "Wireless Sensor Network Attacks and Security Mechanisms: A Short Survey", 2010 IEEE.

[4] J. P. Walters, et al., "Wireless sensor network security: A survey," Security in distributed, grid, mobile, and pervasive computing, p. 367, 2007.

[5] Karlof, C. and Wagner, D., "Secure routing in wireless sensor networks: Attacks and countermeasures", Elsevier's Ad Hoc Network Journal, Special Issue on Sensor Network Applications and Protocols, September 2003.

[6] Bo Yu and Bin Xiao, "Detecting Selective Forwarding Attacks in Wireless Sensor Networks", In Parallel and Distributed Processing Symposiun, 2007. ISSNIP 2006, 20th International, page 8 pp., 2006.

[7] Bin Xiao, Bo Yu, and Chuanshan Gao, "CHEMAS: Identify Suspect Nodes in Selective Forwarding Attacks", In Parallel and Distributed Processing Symposiun, 2007.

[8] Tran Hoang Hai and Eui-Nam Huh, "Detecting Selective Forwarding Attacks in Wireless Sensor Networks Using Two-hops Neighbor Knowledge" Seventh IEEE Internation Symposium on Network Computing and Applications, 2008, pp.325-331.

[9] A. da Silva, M. Martins, B. Rocha, A. Loureiro, L. Ruiz, and H. Wong, "Decentralized intrusion detection in wireless sensor networks", international workshop on Quality of service & security in wireless and mobile networks, 2005.


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Dr. Elleithy has more than 25 years of teaching experience. His teaching evaluations are distinguished in all the universities he joined. He supervised hundreds of senior projects, MS theses and Ph.D. dissertations. He supervised several Ph.D. students. He developed and introduced many new undergraduate/graduate courses. He also developed new teaching / research laboratories in his area of expertise.

Dr. Elleithy is the editor or co-editor for 12 books by Springer. He is a member of technical program committees of many international conferences as recognition of his research qualifications. He served as a guest editor for several International Journals. He was the chairman for the International Conference on Industrial Electronics, Technology & Automation, IETA 2001, 19-21 December 2001, Cairo – Egypt. Also, he is the General Chair of the 2005-2014 International Joint Conferences on Computer, Information, and Systems Sciences, and Engineering virtual conferences.

# Brain Signals Analysis during Meditation and Problem Solving

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## Abstract

Improving performance is one of the hot topics in every industry. Researchers are working on many perspectives to achieve ideal results to improve performance. Some of them study external factors while others focus on internal factors regarding performance. They consider it an essential base to affect subject productivity. However, relaxation, calming down, and confidence play major roles in refining the efficiency of people's productivity. This paper concentrates on the internal factors of individuals observing their performance during activity. It then analyzes brain signals during meditation and solving math problems by observing signals from the cerebral cortex of the participant using electroencephalography (EEG). Mastering the subconscious leads to improving subject productivity and performance. A person can change their habits and better themselves without using chemicals or drugs, and everything depends on a self-anchor. Meditation gives direct access to hidden power and forces the mind to act differently to gain strength reducing pain and stress and can be a self-anchor.

## Keywords

Electroencephalography (EEG), Meditation, Stress, Relaxation, internal factors

## Introduction

The brain is the center of commands and is the decision maker. Scientists found that controlling and understanding brain signals will help people change their life for the better without the necessity of chemicals or drugs. However, the brain's cerebral cortex structure is divided into four lobes (Frontal lobe, Parietal lobe, Occipital lobe, and Temporal lobe.) Each lobe is responsible for performing different functions. When the brain shifts from one stage to another it generates various waveforms (Beta, Alpha, Theta, Delta, and Gamma) with unique amplitudes, and frequencies. Each waveform indicates certain characteristics and details. Scientists have proven that confidence and relaxation are important elements that affect people's lives directly. Furthermore, they help people to improve faster when people know how to control those components. Learning how to master the subconscious resizes the anxiety, stress and anger issues. That is why development coaches and natural healers teach self-discipline. Psychiatrists believe twisting minds (mindfulness) is real when a person wants to do something and that mindfulness helps to increase the effort. Psychologists concentrate on the same elements when they help smokers to quit. The result after a couple months is that 66% of the group responded positively. In addition, scientists found that the brain communicates with the subconscious. It usually links to pictures and colors more than words to shift from one stage of brain signal to another or from a state of being such as discomfort to comfort and vice versa. For certain, working on internal and external factors is a great combination that makes unstoppable improvement. People that master their comfort experience life changes as a result.

## Related Work

Researchers, neuroscientists, psychologists, and other scientists have devoted much research towards brain signals and the investigation of how the brain relates with psychological and physical aspects. Both consciousness and the body are associated because they affect each other. One study, about the relationship between brain signals and the body investigated heart rate patterns[1]. The results showed notably different effects in the nervous system. Neuroscientists recommend certain activities and sports to trigger the temporal lobe which generates gamma waves[2]. Research exhibits the brain, and classifies more than one source in the brain that generates gamma waves. However, stress and anxiety are reactions reflected on the physical body and through emotions. If they are reduced, and relieved, the body acts differently, even though some people do not know how to manage their emotions and heal their stress[3]. Investigation focused on binaural-beats environment on subjects' alpha waves affected the EEG signal[3]. Twisting mind and mindfulness terminology is used by medical professionals to practice training the brain to act differently compared to real situations. One of these techniques has been used monitoring brain signals and respiration signals during meditation to evaluate body response[4].

## Methodology

### *Participants*

There were 9 participating in this study, including both male and females. They are all 21 or over. They were all voluntarily participating in the study and they each signed a consent form. The participants were informed about the study and its procedure, as well as the aim behind the project before the study took place. They were going to do math problems. After that they were given a break. Next, they were instructed to relax and meditate about things that were occuring in their own lives. Finally, they were asked to do math problems again. Each participant wore a device to monitor the participants' brain signals at all times. Using the results, we will be comparing the brain signals, as well as the time taken with solving problems before and after the meditation.

### *Hardware*

The hardware that's used in this study: Windows 7 pro as the PC's operating system installed on a powerful machine with Intel Core i7 CPU and 16 GB of memory, and Figure 1: BioRadio wireless device (USER UNIT). Figure 2: The metal electro wires attached to the participant's cerebral cortex on the surface without any open wounds. They connected to a BioRaido device. The device was sent the signal wirelessly via antenna. A USB Receiver attached to the PC's to get the brain signals.

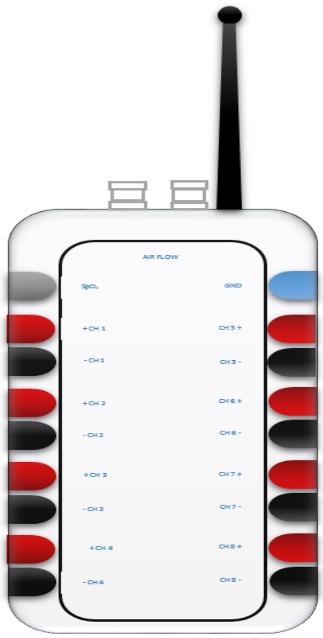

**Figure 1: BioRadio 150 USER UNIT**

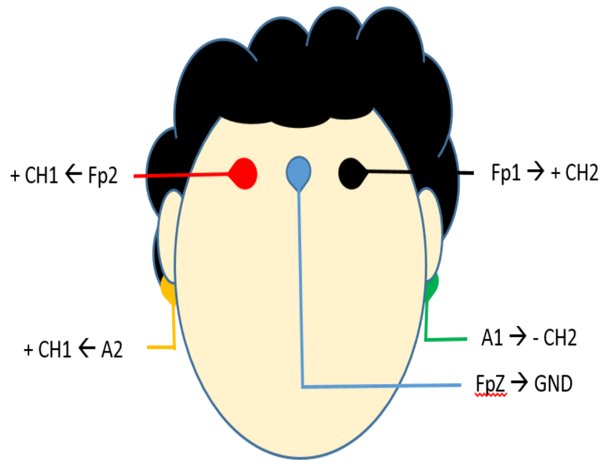


**Figure 2: Place EEG wires**

*Software*

The program’s software being used include the MATLAB 2013a version 64bit that was used in implementation and simulation. BioCapture was used for reading the signals.  Figure 3: Through the use of BioCapture, USER UNITs can be changed for specific input data to read the brain signals. They store data and give the results of the signals received from participants.

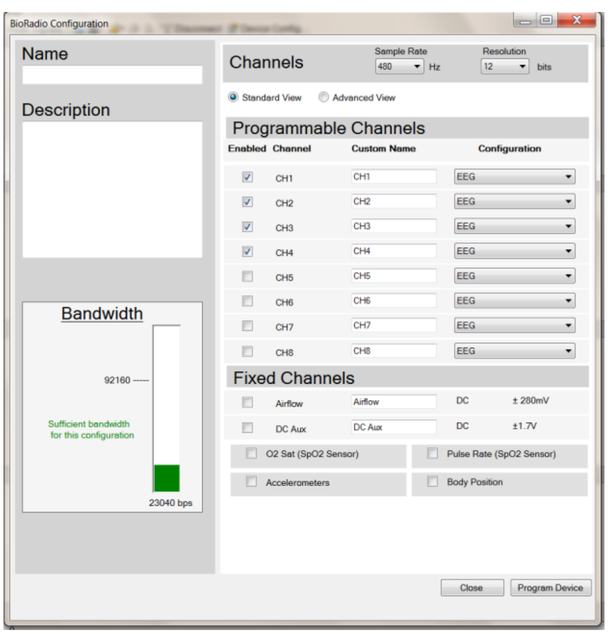


**Figure 3: BioRadio Configuration**

| User Unit | |
|---|---|
| Number of Input | + CH1, - CH1, + CH2, - CH2, GND. |
| Input Range: | ± 750µV |
| Resolution: | 12 bits |
| Noise: | < 2µV peak-to-peak (0.5 Hz – 100 Hz) |
| Sampling Rate: | 480 samples per second per channel |
| CMRR: | >= 90 dB |
| Power Source: | 2 AA |
| Input Impedance: | > 20 MΩ at 10 Hz |
| Filter Input Bandwidth: | 0.5 Hz – 250 Hz (-3dB attenuation |

**Figure 4: USER UNIT Specification**

## Evaluation and Analysis

While the participants solved math problems in an isolated room the investigator observed the participants and monitored the screen with data[6]. Figure 5 shows that the brain signals suddenly changed after answering some math problems. The signals indicated the brain switched from comfortable status to a rough status of thinking, which might indicate deep thinking or a struggle and frustration.

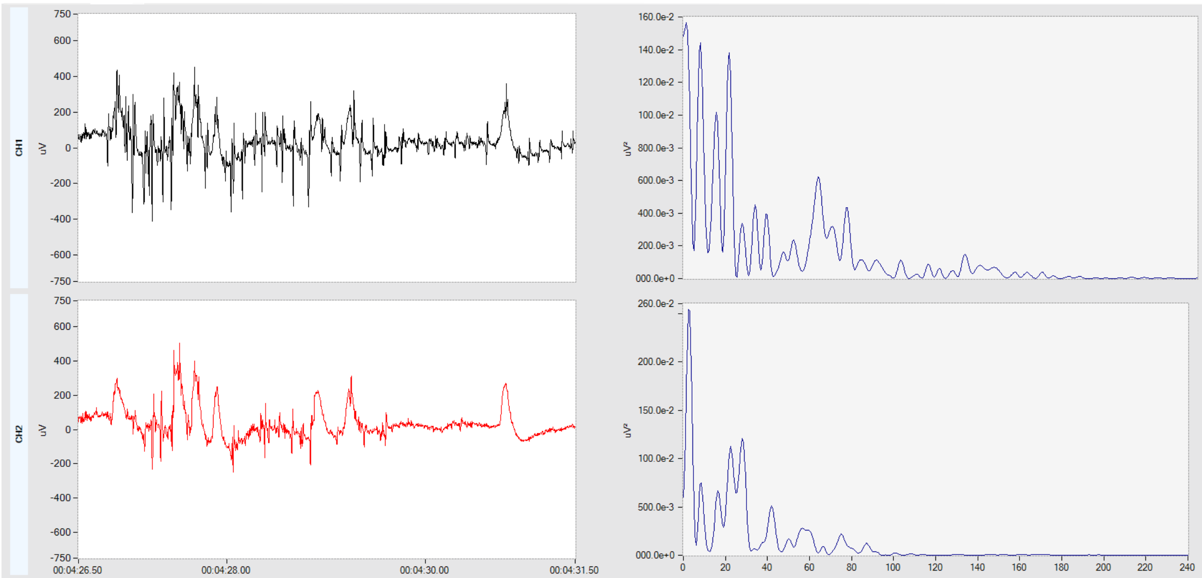


**Figure 5: Brain Signals before Mediation**

Brain signal are completely different during meditation. Figure 6: when participants free their mind releasing stress the brain generates different signals and that indicates the brain shifting from one wave to another with a different amplitude and frequency[7].

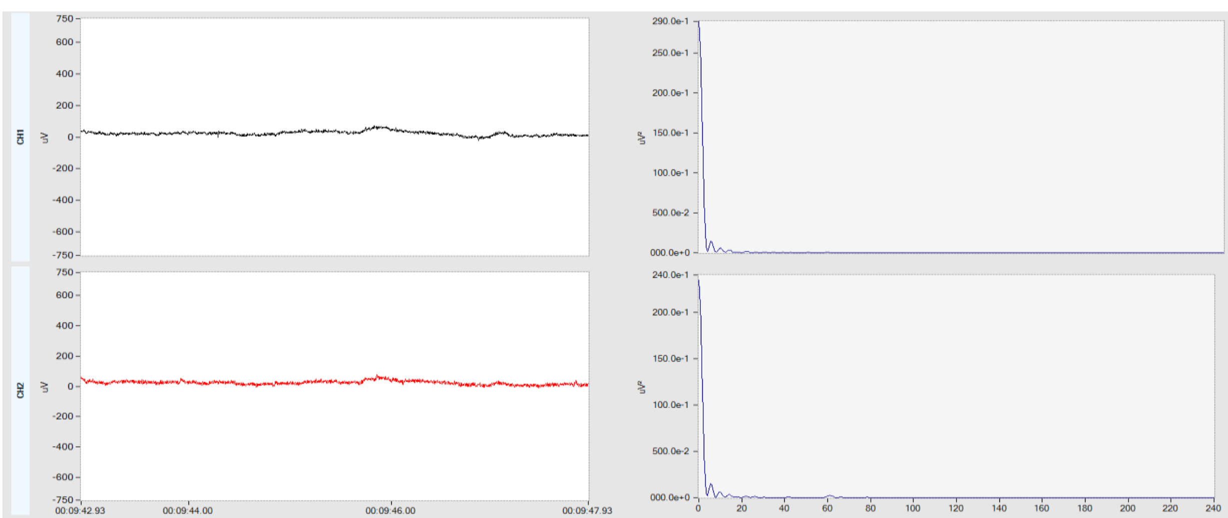


**Figure 6: Brain Signal during Mediation**

People's performances vary differently even though they are facing the same difficulty. Their brain views the situation in a different way. Participants took the same level of math problems and their results improved compared to their productivity before mediation[8]. They were asked to calm themselves down and supervise their brain[9]. Figure 7 shows that the participants' brain signals are smoother compared to the same participant's brain signal in Figure 5.

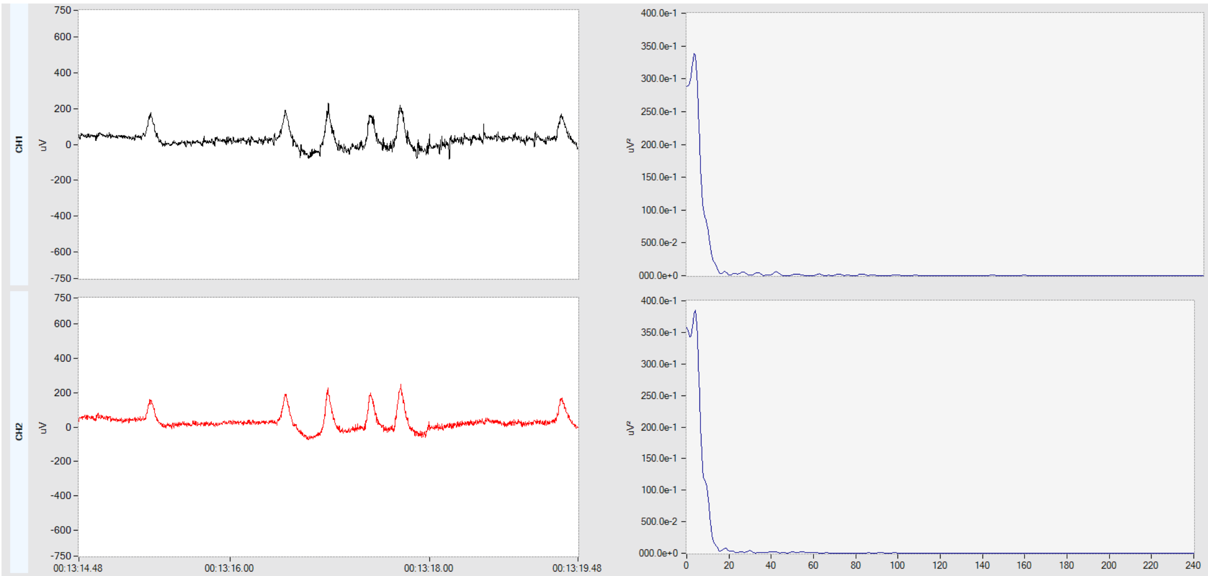


**Figure 7: Brain Signal after Meditation**

## Result

The brain relies on knowledge to deal with life, and stay in a relaxing mode. Sometimes, people need to know how to fool their brain to overcome their obstacles, and gain knowledge in terms of thinking and power in terms of the physical body. However, controlling the subconscious is the ultimate way to achieve a target of life, and success in any challenge. Frustration and struggle are some of the emotions that limit humans' creativity. The hidden power of people's subconscious mind can be reached through meditation. In the experiment people had the same difficulty with math problems. They did better after mediation compared to their work before relaxing.

## Conclusions and Future Directions

By studying brain signals in different phases we can research how they are related to the participants' productivity and see if it will increase the awareness of the brain. It will give us more clues regarding brain functions. The result will lead to better control of productivity. These results are necessary to figuring out how to stimulate relaxation without external influences such as place, material, and moment.

## References


1 S. Phongsuphap and Y. Pongsupap, “Analysis of heart rate variability during meditation by a pattern recognition method,” Computing in Cardiology, vol. 38, pp. 197-200, 2011.

2 M. A. Vazquez, J. Jin, J. Dauwels, and F. B. Vialatte, “Automated detection of paroxysmal gamma waves in meditation EEG,” in Acoustics, Speech and Signal Processing (ICASSP), 2013 IEEE International Conference on, 2013, pp. 1192-1196.

3 H. Norhazman, N. Zaini, M. Taib, H. Omar, R. Jailani, S. Lias, L. Mazalan, and M. Sani, “Behaviour of EEG Alpha Asymmetry when stress is induced and binaural beat is applied,” in Computer Applications and Industrial Electronics (ISCAIE), 2012 IEEE Symposium on, 2012, pp. 297-301.

4 A. Ahani, H. Wahbeh, M. Miller, H. Nezamfar, D. Erdogmus, and B. Oken, “Change in physiological signals during mindfulness meditation,” in Neural Engineering (NER), 2013 6th International IEEE/EMBS Conference on, 2013, pp. 1378-1381.

5 R. F. Ahmad, A. S. Malik, N. Kamel, F. Reza, A. Karim, and A. Helmy, "Simultaneous EEG-fMRI Data Acquisition during Cognitive Task," 2014.

6 V. Mihajlovic, B. Grundlehner, R. Vullers, and J. Penders, "Wearable, Wireless EEG Solutions in Daily Life Applications: What are we missing?," 2015.

7 S. Sahoo, S. Mohanty, and T. Sahoo, "Association between psychology and technical education by EEG," in Advance Computing Conference (IACC), 2014 IEEE International, 2014, pp. 1315-1321.

8 R. Mahajan and D. Bansal, "Hybrid multichannel EEG compression scheme for tele-health monitoring," in Reliability, Infocom Technologies and Optimization (ICRITO)(Trends and Future Directions), 2014 3rd International Conference on, 2014, pp. 1-6.

9 V. Gandhi, V. Arora, L. Behera, G. Prasad, D. Coyle, and T. McGinnity, "A recurrent quantum neural network model enhances the EEG signal for an improved brain-computer interface," in Assisted Living 2011, IET Seminar on, 2011, pp. 1-6.


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# Brain Signals Analysis during Concentrated and Diluted Modes

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*Bridgeport, Connecticut, United States*

## Abstract

One way of avoiding procrastination is by activating areas within the brain where we switch from one mode of thinking to another. Scientists say the primary cause of procrastination is that people tend to become uncomfortable when they are not sure what to do. However, the discomfort can be changed. Scientists have found that stimulating the brain from an unpleasant to a happy thought is possible by fooling the brain, even it is temporary. This study focuses on brain signals during people's interaction with non-familiar situations (diluted mode), monitors their performance during familiar activity (concentration mode), and analyzes their performance. Cerebral cortex signals are analyzed from the participant using electroencephalography (EEG). The brain can be trained to deal with unexpected scenarios that lead to frustration. This study can help improve a person's life by training their brain to take proper action to deal with their discomfort.

## Keywords

Electroencephalography (EEG), Concentrated, Diluted, Relaxation,

## INTRODUCTION

The human brain is much more complicated than a machine; it is intelligent and learns on a daily basis. The brain adapts to new things, from education; to the way one lives; to the way one may react in various situations. According to neuroscientists, the brain has two different ways or modes of thinking. The first of the two modes is the concentrated mode; this is when a person is focused. The second mode is the diluted mode, which is when a person diffuses information to discover new techniques to solve a problem. The brain cannot be in both modes at the same time. When people deal with familiar situations their brain is in concentrated mode; attempting to recognize and study patterns. As soon as they are faced with a new situation that requires a new approach to solve the problem, the brain switches to diluted mode. The brain attempts to generate a new solution by thinking in different ways. The brain absorbs new techniques to learn more ideas, solutions, and methods. This absorption helps to reduce frustration, struggle, and also improves skills in an efficient way. However, the brain needs training in order to control frustration. It does this by fooling the subconscious into switching modes in order to focus within the concentrated mode. By learning how to switch modes, the brain is implementing methods to approach mind power, increasing confidence to look at the problem from a different perspective.

## Related Work

Researchers announced brain training improves access to different modes of thinking which helps to control frustration[1].When people are attempting to figure something out, they usually associate things that are familiar to them. Neuroscientists have detected that the diluted mode is most powerful when the brain determines a new strategy with an unknown scenario. This mode of thinking changes the brain from relaxation to frustration status[2]. Psychologists confirm that the brain can analyze any sudden situation. The brain then gives better performance if it is familiar with the situation or a similar scheme[3].

## Methodology

*Participants*

There were 10 participants in this study, including both males and females. Participants were all over twenty one. All participants voluntarily participated in the study and each signed a consent form. The participants were informed about the study and its procedure, as well as the aim behind the project before the study took place. Participant brain signals were recorded throughout the study using a monitoring device. First, the participants were asked general questions about themselves, then questions of a more personal nature. Next, the participants were instructed in methodologies of how to deal with unexpected situations. Finally, they were asked to repeat the procedure again. The data will compare the brain signals, as well as the time taken to answer questions before and after training.

*Hardware*

The hardware used in the study: Windows 7 pro as the PC's operating system installed on a powerful machine with Intel Core i7 CPU and 16 GB of memory, and BioRadio wireless device (USER UNIT). The metal electro wires were attached to the participants' cerebral cortexes on the surface without any open wounds. They were connected to a BioRaido device. The device sent the signal wirelessly via antenna. A USB Receiver was attached to the PC to capture the brain signals.

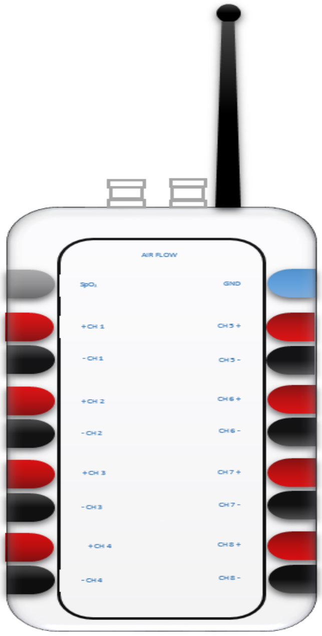

Figure 1: BioRadio 150 USER UNIT

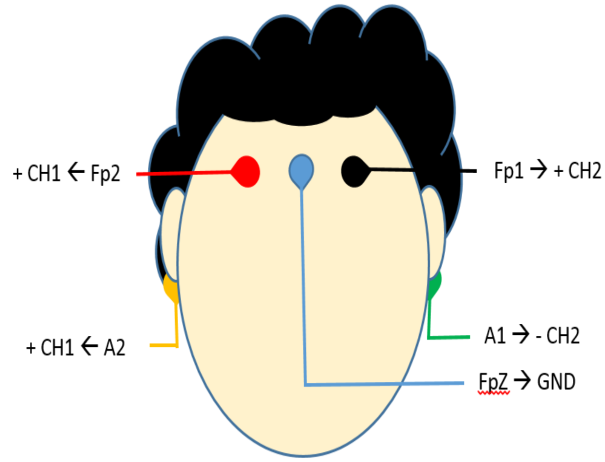


Figure 2: Place EEG wires

*Software*

The program software being used includes the MATLAB 2013a version 64bit that was used in implementation and simulation. BioCapture was used for reading the signals. Figure 3: Through BioCapture, USER UNITs could be changed for specific input data to read the brain signals. They store data and give the results of the signals received from participants.

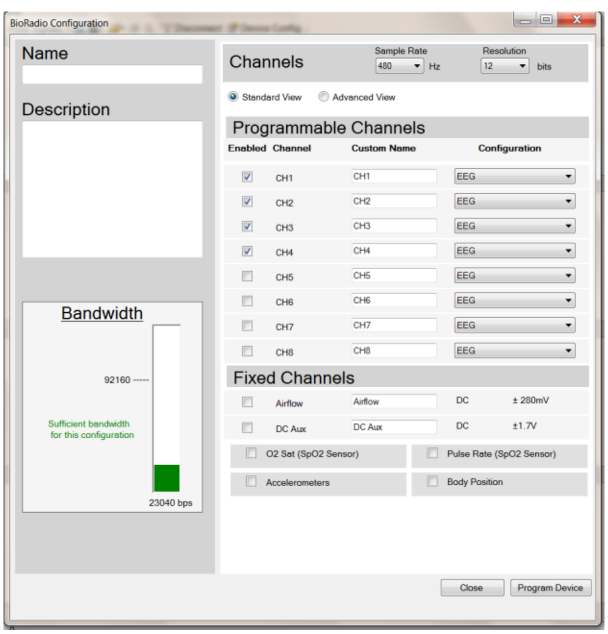


Figure 3: BioRadio Configuration

| User Unit | |
|---|---|
| Number of Input | + CH1, - CH1, + CH2, - CH2, GND. |
| Input Range: | ± 750µV |
| Resolution: | 12 bits |
| Noise: | < 2µV peak-to-peak (0.5 Hz – 100 Hz) |
| Sampling Rate: | 480 samples per second per channel |
| CMRR: | >= 90 dB |
| Power Source: | 2 AA |
| Input Impedance: | > 20 MΩ at 10 Hz |
| Filter Input Bandwidth: | 0.5 Hz – 250 Hz (-3dB attenuation |

Figure 4: USER UNIT Specification

## Evaluation and Analysis

People were born alike, but their personalities are formed based on environment and life experiences. However, the brain is able to adopt new characteristics every time, so the person is not the same after facing different circumstances. In this study when participants were asked general questions, which had multiple possible answers the participants felt comfortable answering.[4,5] As soon as they asked narrow questions, their brain reacted and produced different signals that indicated the participants' brain switched from concentrated mode to diluted mode. This reaction might be due to the participants concern about the type of answer and that is similar behavior to procrastination in a real life situation [6].

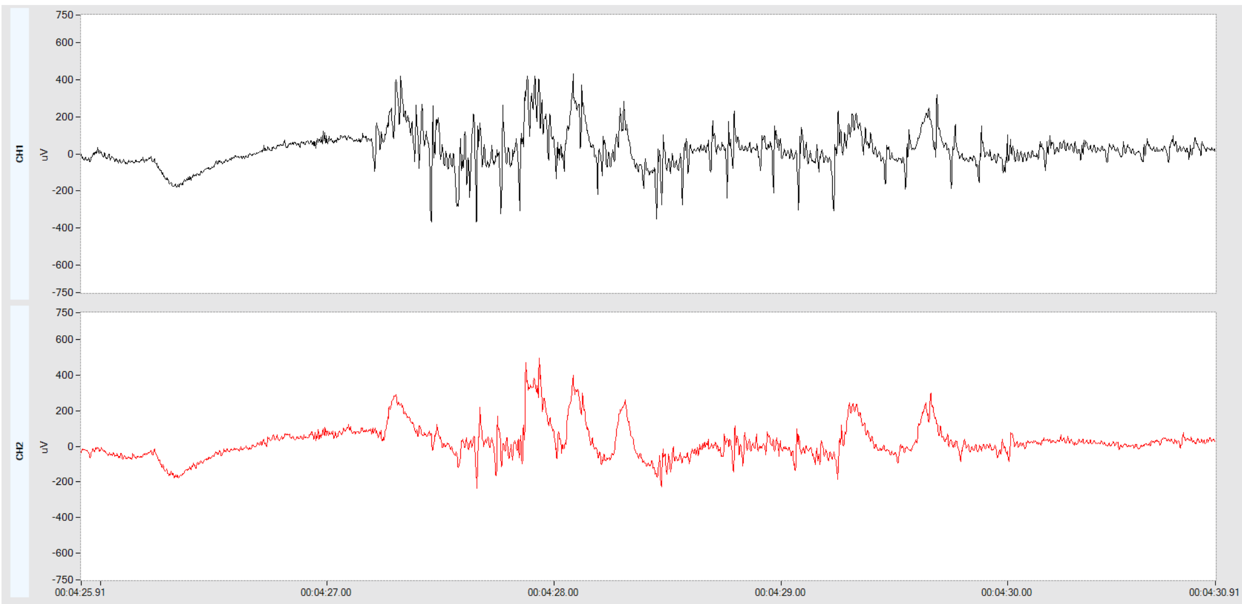


**Figure 5: Brain Signal before Training**

The brain always refers to life experience and knowledge to deal with similar circumstances. The brain possesses information that helps people to control their frustration and to switch their brain mode[7,8]. Investigators gave advice to participants on how to overcome surprise questions, which caused their struggle[9]. Figure 6 shows brain signals are less scrambled when comparing their signals before they received tips on how to deal with surprise situations.

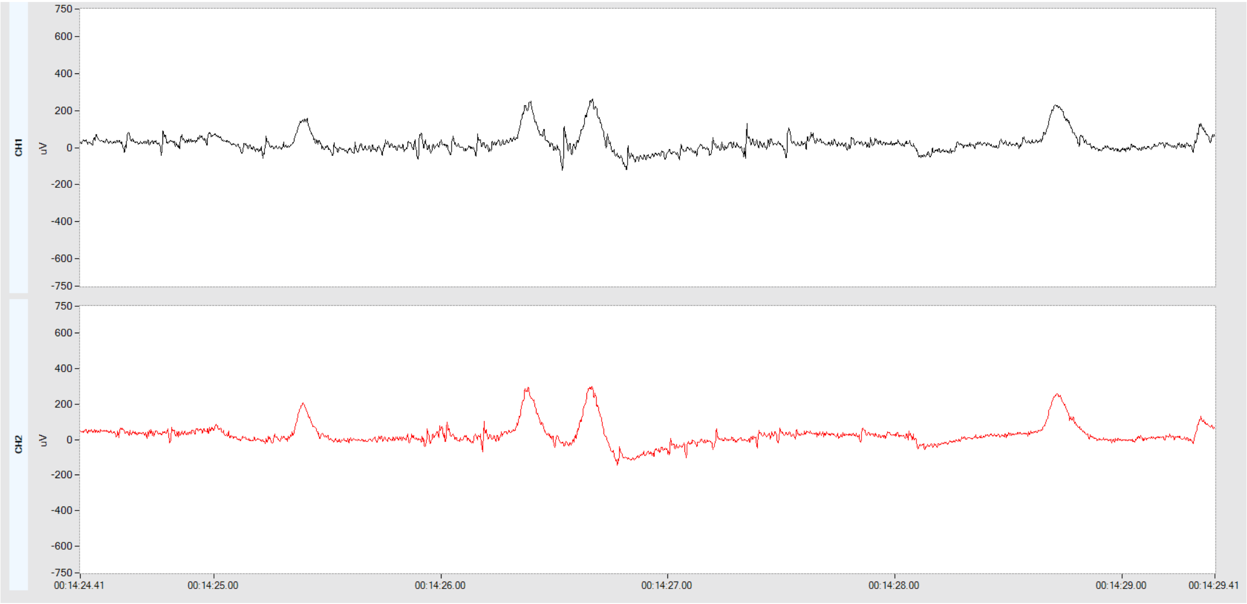


**Figure 6: Brain Signal after Training**

## Result

Accessing different modes of thinking requires training. By default, people's brains are in concentration mode, and they transform to diluted mode when their brain invents a new idea, or thinks of a different solution. The results of the study show that while participants were relaxing, their brain signal produced ± 200 μV, and that is considered an average voltage. When they are out of their comfort zone, the brain signal frequency increases to almost twice as high as the normal status due to lack of confidence, frustration, or knowledge. However, when participants gain some guidance and knowledge their chance of mastering their fear of a surprising situation will escalate.

## Conclusions and Future Directions

Studying brain signals in different modes helps us to understand the factors of procrastination and the delay of taking action when thinking. It also helps us comprehend the brain, how it functions, and to solve the mystery of different modes. This will give us insight on how to improve our lives by accessing modes to reduce frustration and increase confidence. Studying brain behavior and understanding it in depth leads to better advice, and training to prevent procrastination of a powerful mind

## Acknowledgement

Especial thanks of the author Peter W. Murphy using his book techniques and strategies "Always Know What To Say - Easy Ways To Approach And Talk To Anyone" with our participants during training

## References

1 K. Amarasinghe, D. Wijayasekara, and M. Manic, "EEG based brain activity monitoring using Artificial Neural Networks," in Human System Interactions (HSI), 2014 7th International Conference on, 2014, pp. 61-66.
2 N. Dobashi and K. Magatani, "Development of the EEG measurement method under exercising," in Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE, 2009, pp. 380-383.
3 C. Escolano, M. Aguilar, and J. Minguez, "EEG-based upper alpha neurofeedback training improves working memory performance," in Engineering in medicine and biology society, EMBC, 2011 Annual International Conference of the IEEE, 2011, pp. 2327-2330.
4 S. Jirayucharoensak, P. Israsena, S. Pan-ngum, and S. Hemrungrojn, "Online EEG artifact suppression for neurofeedback training systems," in Biomedical Engineering International Conference (BMEiCON), 2013 6th, 2013, pp. 1-5.
5 K. Li, G. Sun, B. Zhang, S. Wu, and G. Wu, "Correlation between forehead EEG and sensorimotor area EEG in motor imagery task," in Dependable, Autonomic and Secure Computing, 2009. DASC'09. Eighth IEEE International Conference on, 2009, pp. 430-435.
6 C.-T. Lin, C.-H. Chuang, C.-S. Huang, S.-F. Tsai, S.-W. Lu, Y.-H. Chen, and L.-W. Ko, "Wireless and Wearable EEG System for Evaluating Driver Vigilance," Biomedical Circuits and Systems, IEEE Transactions on, vol. 8, pp. 165-176, 2014.
7 D. Wulsin, J. Blanco, R. Mani, and B. Litt, "Semi-supervised anomaly detection for EEG waveforms using deep belief nets," in Machine Learning and Applications (ICMLA), 2010 Ninth International Conference on, 2010, pp. 436-441.
8 H. Xia, D. Ruan, and M. S. Cohen, "Coupled basis learning and regularized reconstruction for bcg artifact removal in simultaneous EEG-fMRI studies," in Biomedical Imaging (ISBI), 2013 IEEE 10th International Symposium on, 2013, pp. 986-989.
9 F. Yan, P. A. Watters, and W. Wang, "Determining the influence of visual training on EEG activity patterns using association rule mining," in Complexity and Data Mining (IWCDM), 2011 First International Workshop on, 2011, pp. 64-67.

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# Improving Global Healthcare by Focusing in Quality

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## Abstract

Global health care can be improved through the use of sound quality management strategies. Health care quality is defined as the ability of the facilities to provide safe medical care to patients and achieve the anticipated health outcomes. The main quality aspects in healthcare include: patient safety, effectiveness, patient centered services, the ability to provide health care services to the patient on time, efficiency and equity. Previous research and cohort studies document the use of quality as a vital tool in global health. These researches raise a number of issues that can be used to improve quality.

In this paper, a systematic literature review was conducted. Data was collected from already published materials on health care quality. The data was analyzed through content analysis to determine the major perspectives. The results indicate that the main quality aspects that improve global health are the use of information technology and e health solutions, use of strategic human resource management, training health care workers, reducing disparities when providing healthcare services, developing good policies that improve healthcare quality, use of evidence based practice, improving the medical service efficiency and patient safety.

## Keywords

Global Healthcare, Quality Aspects, Information Technology, and Healthcare Quality.

## Introduction

Quality improvement is the central focus in many health care institutions and among policy makers. Quality can be defined as the probability of achieving the anticipated health outcomes that are consistent with the current professional practice and patient demand. The main aim of healthcare quality is to enable people achieve a healthy, safe and longer life span. Quality in healthcare therefore determines the level of excellence exhibited by the service providers and facilities. Healthcare quality is expressed in terms of safety, effectiveness, patient centered services, the ability to provide health care services to the patient on time, the level of efficiency and equity[2].

In terms of safety, the health care facilities must provide services that prevent death and bodily harm to their patients. In terms of effective services, these facilities must provide services that follow and uphold the general scientific knowledge. In addition, the services must be beneficial to the patients. The services provided must put a lot of emphasis on the patients and be responsive to their needs. The services must be provided on time to avoid the patients suffering or their condition worsening. Health care services must also be efficient and avoid wastes by using lean methods. Lastly, the services must be equitable as this ensures that there are no disparities in the quality of services to different people. The healthcare facilities and services can be improved globally through quality improvement. This is done through a number of strategies which guarantee the patients safety and prevent the occurrence of new diseases.

This report focuses on strategies that improve global health though quality improvement. The paper identifies the main strategies used to improve health care quality through a systematic literature review of the current publications in the health care industry. The paper also stipulates quality measurement methods and the impediments that policy makers and other healthcare professional face when improving quality. Through the use of systematic literature review, the research identifies the current global problems and methods through which quality improvement results better global health care.

## Literature Review

This literature review discusses in great details the publications on the recent trends in global healthcare quality. Studies on the issue of healthcare quality were analyzed in order to identify the current cross cutting issues.

Black, A.D., et al.[3] investigated the impacts of quality and safety in health care when using Internet and IT (information technology) solutions. Using a systematic literature review, the study found out that e health played a significant role in improving the storage and retrieval of medical information, assisting doctors and healthcare practitioners when making decisions and in providing healthcare to patients located in remote locations. The research however found out that most policy makers have a problem in quantifying the benefits of e health and cannot therefore solicit enough funding and support to implement such systems. Poon, E.G., et al.[25] document that the uses of modern IT solutions and bar code readers have significantly improved procurement and administration of prescriptions. Bar codes verify medications preventing errors and enhancing the patient's safety. Studies by Ammenwerth, E., et al.[1] document the importance of modern IT in improving global healthcare through enhancing the quality of service delivered, improving medical service efficiency and reducing the overall costs. Chaudhry, B., et al.[8] found out that IT solutions improve the service quality and reduce administration costs in most health care institutions. Bryan, C. and S.A. Boren [6] found out that computerized systems, IT and ehealth solutions improve the health quality by assisting in information storage, retrieval, decision making and providing solutions to patients in remote location. Ovretveit, J., et al.[21] investigated the importance of information technology in improving the quality of healthcare. Their study showed that IT improved communication and flexibility among the healthcare workers. Various studies also document that use of IT improves communication, teamwork, corroborations and the general healthcare quality globally. Ludwick, D.A. and J. Doucette[17] conducted a study on the impact of information system on health care in seven countries. Their study indicate that such system improve quality, procurement, patient privacy, record keeping, efficiency and reliability. Though many studies indicate the importance of e health systems in quality improvement, few studies document the risks that health care facilities face when installing such systems. In addition, few studies quantify the benefits achieved by implementing such systems. It is therefore imperative to carry out this research to evaluate the benefit of e health in light of major impediments such as risks, costs and capacity[4].

Human resource development and improvement in most health care facilities improves the quality of care provided. Lack of adequate training and motivation among health care workers affect the service quality. Gowen, and Tallon[13] conducted a study to evaluate the importance of good human resource management (HRM) in improving the quality of health care. In their study, medical practitioners from 587 facilities in the USA were issued with questionnaires. The study found out that there exist a strong positive correlation between the health care quality, number of errors during treatment and the overall efficiency of the service provided. Research by Chen, L., et al.[9] evaluated the impact of global healthcare capacity on healthcare quality. The research documents that building human resource competency and capacity is pivotal in achieving better global care. In the developing countries, the doctor and nurse to patient ratio is very low and this increases the health problems in primary healthcare institutions. The study document other problems associated with inadequate HRM as low skills, skilled employee shortage, unequal worker distribution, poor working conditions and susceptibility of the healthcare workers to contagious diseases. The research indicate that the global HRM problem can be solved through effective national strategies and international collaboration, shared responsibility and improving the skills of workers globally. Rowe, A.K., et al.[26] states that poor developing nations have low performing workers with very poor healthcare skills. This in turn affects the service quality and impede on good healthcare. This study states that international interventions to improve global health in these countries are not effective and there is need to formulate better multifaceted interventions that target a specific locality. The study indicates that health ministry's research findings should be used to improve local and national health quality. Healthcare workers performance is imperative in the achievement of millennium development goals. Strategic HRM improves workers skills and performance but this varies between different countries and yields different results globally. From the study, there is need to localize HRM issues, motivate workers towards change and create awareness about the local issues affecting healthcare. The medical health quality is directly influenced by worker satisfaction and therefore strategies of empowering employees in hospitals should be instituted to improve global health. Campbell, S., et al.[7] investigated the impacts of pay based on performance in the UK. Their study found out that these pay system was associated with increased improvement in management of chronic illnesses and professional conduct.

Drain, P.K., et al.[11] document that training and educating workers plays an important role in improving global healthcare. Their study indicates that international immigration increases the spread of diseases and this have increases the global burden for contagious and chronic illnesses. To circumvent this problem, workers must be trained on new international health issues from different social cultural perspectives. International health Workers rotation program should be instituted to improve the knowledge among the practitioners. Nelson, B.D., et al.[20] states that global pediatric health programs can improve the quality of care as workers become knowledgeable in new global challenges and issues.

Ovretveit, J., et al.[21] carried out a research to determine the global impacts of unsafe healthcare and its impacts on quality. Their research found out that unsafe healthcare increases morbidity and mortality at a global level. The study found out that over 16% of the patients suffer harm from unsafe health treatment. Various studies also show that unsafe medical care increases the diseases burden, cost of hospitalization and reduce healthcare burden. Studies by Braithwaite, J., et al.[5] focused on identifying ways of improving health care quality inquired from over 2000 healthcare workers in South Australia. Their research sought to determine major ways through which patient safety could be improved. The results show that different employees have varying perceptions on patient safety and this impedes the successful quality improvement. The main healthcare quality suggested by these workers were: improve infrastructure, capacity building by increasing the number of healthcare workers, formulating and implementing policies, educating health care workers, focus on patient, better leadership and management and lastly, improving communication and teamwork. Landrigan, C.P., et al.[16] conducted a study to determine the impacts of harm caused to inpatients in ten North Carolina hospitals selected using stratified random sampling. The research showed that low quality services expose patients to harm and there has been no significant improvement. This calls for the development of better measurement, policies and tools for improving safety.

There is need to use findings from international and national studies in improving global health care[12]. This requires collaboration, partnering and development of national and international policies to address the current global healthcare problems. The study indicates that the main strategies for improving healthcare are formulating health strategies and interventions, using appropriate technologies, designing proper healthcare systems (HRM, procurement, information management and service delivery), developing better primary and secondary care facilities, providing good leadership and educating workers.

Studies by Marmot, M.[18] stated that there is need to strengthen global and national health equity. Health care should not be discriminatory and should be accessed by all disregarding their social economic status. Starfield, B.[29] stated that global health care presents many challenges in terms of equity, healthcare costs, population, disease morbidity age and technological interventions. All these issues greatly correlate with equity and results to disparities in health care provision which in turn affect quality. Patouillard, E., et al.[23] stated that the use of private and nongovernmental organization (NGO) in poor and developing nations could improve the healthcare quality. A systematic literature review on interventions by NGO among the marginalized communities' showed an improvement in healthcare quality and equity. However, private health institutions did not improve health care equity and service quality among the poor residents.

Delivering medical services on time has great impacts on the health care quality. Sofaer, S. and K. Firminger[28] investigated the patient perception on health care quality. Among the main patient quality requirement was timely service delivery. Studies by Poissant, L., et al.[24] documented that the use of electronic systems and records greatly increase time efficiency by significantly reducing the documentation time, record search and retrieval processes. Kerber, K.J., et al.[15] document that lack of timely service delivery is the leading cause of death among antenatal and postnatal mothers as well as infant and newborn babies. This problem is persistent in communities located in remote locations in the developing nations where primary healthcare facilities are far.

## Study Objectives

The primary objective of this study is to identify quality aspects that result to improvement in global healthcare. The research mainly focused on issues that address the current healthcare quality issues and ways of improving them. This study investigated the main quality issues that primarily influence global health care, their relative importance and impacts on global healthcare.

The secondary objectives for the study include:
To conduct an in-depth literature review on the main quality aspects suggested by previous studies.
To identify the main quality issues affecting healthcare- this will be done through a systematic literature review on healthcare studies around the world.
To elucidate the impacts of these quality aspects on global health care.
To stipulate strategies that can be used to improve the identified quality issues.
To prepare a discussant detailing the current research findings, a comparative analysis of the current study finding with previous studies.
The paper will also suggest future research and studies in this field.

## Research Methodology

A qualitative study methodology was used for research paper. According to w Creswell[30] a qualitative study develops knowledge based on constructivism and interpretivism perspectives. In qualitative method, the researcher develops knowledge based on the people's understanding about a given situation. The method is widely used to study social issues such as healthcare quality perception among people. The study methodology develops a pattern or theory from the existing knowledge or from people view about a given phenomena. Most of the quality issues in healthcare are based on patient and healthcare workers perception and therefore, this is the most suitable study methodology[10].

Under the ambit of qualitative research method, a systematic literature review on cohort studies done between 2005 and year 2013 was used as the study design. The systematic literature review extracts information from the already published materials on a given study phenomenon. The main justification for using this method is that it gives detailed information about a particular study topic.

A systematic review study design entailed the formulation of the study questions that were pertinent to the research objective, searching for relevant articles based on a developed search criteria, selection of the study articles using a predetermined inclusion criteria, analysis of these articles through content analysis and stipulating the research findings[22].

The main steps in this paper include:

a) Question formulation for the researcher; this entailed the formulation of pertinent study questions; these include: (i) what are the main quality aspects that affect global healthcare, (ii) How do these affect the progress of healthcare institutions, (iii) How can global healthcare be improved through enhancing quality.

b) Literature search: a detailed literature search from major electronic databases was then done. The keywords were "global healthcare through quality", "quality aspects in global healthcare", "information technology", and "healthcare quality".

c) Selecting articles: more than 25 articles were selected using a predetermined inclusion criterion. All articles would be between 2005 and 2014 were included in the study. Articles dealing with healthcare quality, cohort studies on healthcare quality were also included for analysis.

d) Analysis: the articles selected for the study were analyzed using content analysis. This entailed a detailed study of the article to establish the main points. This was followed by cording process which extracted the main quality issues documented in each article. After this, summary will be categorized into groups. These enabled the researcher determine the main quality aspects and their relative impacts on global health care.

**Results and Discussions**

**a) Information Technology**

Most of the articles reviewed showed that information technology is imperative in improving global health quality. Health information technology solutions improve quality as well as reducing cost. The use of IT has also lead to reduced medication errors making it possible to provide quality, up to date and accurate services. With the proper combination, quality of service is guaranteed and operation cost reduced. The reviewed articles indicate that the main uses of IT in improving health quality include: use of electronic records which reduce stress and workload of manual record keeping and prescription; ensuring proper coordination between caregivers and patients thus improving the quality of service offered; assist in health care decision making and bio-surveillance which assist in reducing the reliance on paper charts notifying recalls. Previous literature also document the vital role played by IT in improving healthcare quality, improving timely service delivery and reducing costs.

**b) Improving health equity**

The articles reviewed also showed that reducing health service disparities is important in achieving quality. In the developed and developing nations, the services provided to patients are greatly influenced by racial, ethnic and economic class of the patient. Inequalities in the quality of health are magnified in low-income societies as compared to developed societies. There is a life expectancy difference of more than 20 years between some developed and middle-income economies. To reduce this gap, organizations such as the world health organization have started investigations on the social factors influencing health care provision. The general concept is that the financial stability increases the likely hood of better health services[19].

**c) Training health care workers**

The articles reviewed also indicated that training and education were pivotal in improving global health quality. Training health care providers on leader ship skills imparts a deeper sense of responsibility and commitment to improvement of global health care services. It also trains the providers on effective decision-making skills based on scientific concepts. Training promotes teamwork and personal initiatives in the workplace as well as improves the workers and patients safety. Effective technical and leadership skills must be imparted to health care service providers including nurses and support staff. Training also enables creation of effective organizational cultures that are aimed at improving the quality of health care to patients. For quality and patient centered care to be delivered, professional training should be carried out as an ongoing process to provide opportunities for career growth and job satisfaction. Deeper training on basic concepts of medical care will ultimately contribute to improvement of quality in global health care.

**d) Improving patient care and safety**

The other factor that influences global health is the patient safety and care. Most reviewed researches show that patient care and safety is closely related to cost, the competency of health care workers, level of motivation and the care facility equipment. Patients from low income areas are unable to access quality healthcare. A conducive working atmosphere such as the patient to nurses ratio, appropriate funding by the government, involvement of nurses in the decision making process and a good doctor to nurses relationships contribute significantly to care given to patients as well as their personal safety[16]. Hospitals and nations which regard patient safety and care as imperative have recorded improved healing process, reduced mortality and patient satisfaction. Most studies indicate that there are many deficiencies in the quality of care given to patients across the globe.

**e) Human resource management (motivating, appraising and empowering workers)**

Organizational change can be an effective tool in the improvement of quality in the health care system. Human resource management techniques have been shown to establish and strengthen the conduct of professional health care services. HRM improves health care, enables career development, appraises and motivates healthcare employees and results to these workers offering quality and professional health care. The human resource managers must allow workers to achieve personal objectives as well as organizational objectives for patient care to improve significantly.

**f) Offering effective services**

The articles reviewed in this study document that good and effective services are paramount to improving healthcare quality. Effective service delivery in the medical industry is influenced by factors such as: availability of drugs, equipment, government funding, adequate staffing and professionalism. Other nations have adopted policies where improved performance of certain departments has rewards and incentives to motivate staff for continued performance.

**g) Encouraging the use of Evidence Based Practice**

Evidence based practice is a concept that can be applied to effectively improve the quality of health care provided in the institution and even globally. It is founded on the precept that scientific evidence must be applied as much as possible and the patients' preferences must be put into consideration. The evidence to be applied however depends on the level of training of the medical practitioners as well as their experience. Application of evidence-based practice to improve the global health care must be based on documented and accepted evidences due to the variability of evidence observed by practitioners. Incorporation of the patient's preferences ensures that their opinions are inculcated in the decision making process and this improves healthcare. Cooperation between patient and doctors lead to improved health care provision.

## h) Research and Training

Research and training are central in achievement of quality health services. Health care research can vary in the domains and research aimed at improving care must focus on the key elements. These include how the population access health care services, the cost of obtaining the medication and the derived benefits such as reduced mortality and quicker recovery. Due to global variability, there is need for collaborations so that scientist and medical practitioners can share vital information to reduce disease morbidity, mortality and burden.

## i) Developing adequate global healthcare policies

The policy framework is crucial in determining factors which adversely affect the health care system. Policies affect the financing and resource allocation by governments and provide main focus areas. Global quality of health is an issue requiring a lot of attention. The nation's performance in disease prevention and control is greatly affected by its ability to institute appropriate policies.

## Conclusions and Future Research

The management of the global health care system is becoming a concern to many governments. Various researches have also been conducted on the issue of the quality of the global health care services. Various measures have been advocated through research on critical areas of focus to achieve a turnaround in health care service provision. Investment in information technology systems for provision of health care is vital for medical processes such as samples analysis, monitoring of body conditions and patients surveillance. Studies have shown that poor information technology infrastructure is synonymous with poor quality health care provision.

Equitable distribution of health care services is another key pillar over which quality of health care can be managed. This means the government and health care providers ensures policies are formulated while considering the underprivileged people in order to reduce health care disparities.

The use of accurate measurement techniques is also crucial in delivery of high quality health care services. Various quality aspects must be measured accurately and ways of improving these aspects determined.

Training is another important factor used in achievement of quality health services. Training of nurses for leadership and technical skills enhances their performance at work and better patient care. In addition, all healthcare workers must be well and frequently trained to cope with the changing health issues and challenges. Health care workers and particularly nurses need to be trained on leadership and management as these translates to better productivity and improved patient care. In addition to training, these workers need to be empowered and motivated so as to deliver the expected quality. Payment related to performance and appraising medical staff regularly will go a long way in ensuring that workers deliver and guarantee the patient safety.

Evidence based practice is another recommended strategy for global improvements in the provision of health care. This is whereby factual evidence collected and used in decision-making.

Learning from practical examples from other parts of the world will lead to effective formulation and implementation of health care policies and interventions.

Research on the improvement of quality of health care continues with the technological advancements be given more focus. Information technology still remains the area of key focus on the improvements in the delivery of health.

## Future research

This study and other studies documented in the literature review used a systematic literature review to study global health quality. There is need for practical cohort studies in various countries to document the actual quality issues and their impact on health care.

There is need for randomized control trials to test the strategies used to improve global quality. These tests should evaluate health quality before and after an intervention strategy to improve quality. The results obtained can be used to determine the effectiveness of each strategy within a given region or locality.

There is need for studies to develop adequate health quality measurement tools that can be used to test healthcare quality. These tools will be very useful in assessing the healthcare quality and formulating intervention strategies.

## References

1. Ammenwerth, E., et al., *The effect of electronic prescribing on medication errors and adverse drug events: a systematic review.* J Am Med Inform Assoc, 2008. **15**(5): p. 585-600.
2. Bate, P., P. Mendel, and G. Robert, *Organizing for quality: the improvement journeys of leading hospitals in Europe and the United States*. 2008: Radcliffe Publishing.
3. Black, A.D., et al., *The impact of eHealth on the quality and safety of health care: a systematic overview.* PLoS Med, 2011. **8**(1): p. e1000387.
4. Blumenthal, D., *Stimulating the adoption of health information technology.* New England Journal of Medicine, 2009. **360**(15): p. 1477-1479.
5. Braithwaite, J., et al., *Improving patient safety: the comparative views of patient-safety specialists, workforce staff and managers.* BMJ quality & safety, 2011. **20**(5): p. 424-431.
6. Bryan, C. and S.A. Boren, *The use and effectiveness of electronic clinical decision support tools in the ambulatory/primary care setting: a systematic review of the literature.* Informatics in primary care, 2008. **16**(2): p. 79-91.
7. Campbell, S., et al., *Quality of primary care in England with the introduction of pay for performance.* New England Journal of Medicine, 2007. **357**(2): p. 181-190.
8. Chaudhry, B., et al., *Systematic review: impact of health information technology on quality, efficiency, and costs of medical care.* Annals of internal medicine, 2006. **144**(10): p. 742-752.
9. Chen, L., et al., *Human resources for health: overcoming the crisis.* The Lancet, 2004. **364**(9449): p. 1984-1990.
10. Denzin, N.K. and Y.S. Lincoln, *The SAGE handbook of qualitative research*. 2011: Sage.
11. Drain, P.K., et al., *Global health training and international clinical rotations during residency: current status, needs, and opportunities.* Academic medicine: journal of the Association of American Medical Colleges, 2009. **84**(3): p. 320.
12. Frenk, J., *The global health system: strengthening national health systems as the next step for global progress.* PLoS medicine, 2010. **7**(1): p. e1000089.

13. Gowen III, C.R., K.L. McFadden, and W.J. Tallon, *On the centrality of strategic human resource management for healthcare quality results and competitive advantage.* Journal of management development, 2006. **25**(8): p. 806-826.
14. Jha, A., et al., *Patient safety research: an overview of the global evidence.* Quality and Safety in Health Care, 2010. **19**(1): p. 42-47.
15. Kerber, K.J., et al., *Continuum of care for maternal, newborn, and child health: from slogan to service delivery.* The Lancet, 2007. **370**(9595): p. 1358-1369.
16. Landrigan, C.P., et al., *Temporal trends in rates of patient harm resulting from medical care.* New England Journal of Medicine, 2010. **363**(22): p. 2124-2134.
17. Ludwick, D.A. and J. Doucette, *Adopting electronic medical records in primary care: lessons learned from health information systems implementation experience in seven countries.* International journal of medical informatics, 2009. **78**(1): p. 22-31.
18. Marmot, M., *Achieving health equity: from root causes to fair outcomes.* The Lancet, 2007. **370**(9593): p. 1153-1163.
19. Marmot, M., et al., *Closing the gap in a generation: health equity through action on the social determinants of health.* The Lancet, 2008. **372**(9650): p. 1661-1669.
20. Nelson, B.D., et al., *Global health training in pediatric residency programs.* Pediatrics, 2008. **122**(1): p. 28-33.
21. Ovretveit, J., et al., *Improving quality through effective implementation of information technology in healthcare.* International Journal for Quality in Health Care, 2007. **19**(5): p. 259-266.
22. Page, D., *Systematic literature searching and the bibliographic database haystack.* The Electronic Journal of Business Research Methods, 2008. **6**(2): p. 171-180.
23. Patouillard, E., et al., *Can working with the private for-profit sector improve utilization of quality health services by the poor? A systematic review of the literature.* International journal for equity in health, 2007. **6**(1): p. 17.
24. Poissant, L., et al., *The impact of electronic health records on time efficiency of physicians and nurses: a systematic review.* Journal of the American Medical Informatics Association, 2005. **12**(5): p. 505-516.
25. Poon, E.G., et al., *Effect of bar-code technology on the safety of medication administration.* New England Journal of Medicine, 2010. **362**(18): p. 1698-1707.
26. Rowe, A.K., et al., *How can we achieve and maintain high-quality performance of health workers in low-resource settings?* The Lancet, 2005. **366**(9490): p. 1026-1035.
27. S, B., *Can health equity become a reality?* The Lancet, 2008. **372**(9650): p. 8-14.
28. Sofaer, S. and K. Firminger, *Patient perceptions of the quality of health services.* Annu. Rev. Public Health, 2005. **26**: p. 513-559.
29. Starfield, B., *Global health, equity, and primary care.* The Journal of the American Board of Family Medicine, 2007. **20**(6): p. 511-513.
30. w Creswell, J., *Research design: Qualitative, quantitative, and mixed methods approaches*. 2009: SAGE Publications, Incorporated.

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# A Data Envelopment Analysis Approach to Evaluate the Efficiency of Service and Delivery Operations

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## Abstract

Data Envelopment Analysis (DEA) is a linear programming based technique measuring the efficiency and the performance of similar entities, aka, Decision Making Units (DMUs), by using pre-determined data that are classified and embedded into the model as input and output. Since DEA is a data dependent technique, the accuracy of the model results are highly correlated with the quality of the data inputted into the model.

The proposed DEA approach calculates the efficiency and performance levels of 20 independent franchise stores (DMUs). In this regard, various qualitative and quantitative data have been collected for each franchise operating in the fast food industry. In order to provide a detailed analysis, various DEA models were utilized to measure the stores' performances from different perspectives.

**Keywords:** Data Envelopment Analysis, Benchmarking, Service Engineering, Performance Measurement.

## 1. Introduction

The concepts of productivity and efficiency have always been and will be vitally important in the competitive business environments, where limited resources exists. Contemporarily, the intense competition forces companies to use their resources in the most effective way. Performance and efficiency analyses are significant management measurement tools to help companies determine the relationships between the outputs produced and the inputs that are exploited in order to obtain these outputs.

Benchmarking and performance evaluations are widely used to improve performance and increase productivity. The service industry, within the franchise chain restaurants, is an ideal industry to apply the Data Envelopment Analysis (DEA) technique for the purposes of internal benchmarking. The justification for this claim is that, while there is a wide range of variances in competition, location, and neighborhood characteristics, each establishment in a chain restaurant still adopts identical menu concepts, standardized operating procedures, decor and design, as well as technology.[1] DEA can assess productivity at the retail firm or store level using multiple inputs and outputs simultaneously. This procedure provides a single relative productivity index that allows managers to implement an analytical and diagnostic tool required to improve productivity of the individual operations.[2]

This paper presents a DEA approach to measure the relative efficiency of 20 franchise stores operating in the fast food industry. The paper is organized as follows: A list of previous studies is given in section 2. Section 3 provides a summary of the DEA approach. The problem description and a case study are the focus of Section 4. Conclusions and thoughts for future research are provided in Section 5.

## 2. Literature Review

*Measuring Efficiency and Performance*

As Kao et al. [3] mentioned in their study, measuring efficiency and performance of the processes in any organization is vital in this highly competitive business environment.[3] Dotoli et al.[4] also explain that today, globalization has led to an increase in competitiveness among companies and organizations at all levels and in all sectors. Therefore it becomes essential to adopt suitable tools to evaluate the efficiency of a process. A comparative example can be given as an organization's ability to transform its input resources into its corresponding outputs in the best possible way. [4] Similarly, Samoilenko and Osei-Bryson [5] claimed that the dynamic nature of the business environment would cause the levels of performance of competing organizations to change over time, and if the efficiency of the competitors has improved, then a productivity-driven organization must respond with its own improvements in efficiency [5].

In their paper, Ismail et al. [6] provided the historical background of the modern efficiency measurement which began with Farrell[7] who defined measurement as a simple measure of a firm's efficiency which could account for multiple inputs. Farrell proposed that the efficiency of a firm consists of two components: (1) *technical efficiency* which is the ability to produce the maximum number of outputs with a fixed number of inputs, and (2) *allocative efficiency* which is the ability to use the inputs in the most optimal proportion, given their respective prices. These measures combined to produce economic efficiency [6]. Müller [8] also gave historical information about efficiency and mentioned that the term "*efficiency"* goes back to Pareto[9] and the extensions of Koopmans[10]. Yadav et al. [11] explained that organizations involved in similar activities can quantify their relative performance by comparing the results with one another and then develop strategic plans for improvements in their performance taking into consideration the best in the class as a benchmark. In this regard, the DEA is probably the most widely used mathematical approach for benchmarking of organizational units [11].

*Benchmarking*

Over the last two decades, DEA has been used as a popular benchmarking technique for performance measurement [12]. In his paper, Mishra [13] mentioned that benchmarking is used by many leading companies such as Xerox Corporation, and American Express in order to excel in their respective industries on a global scale as well as for small and medium size firms [13]. Paradi and Zhu [14] explained that the limitations of ratio and regression analysis have led to the development of more advanced tools for assessing corporate performance [14]. In supporting Paradi and Zhu[14], Lau [12] discussed that based on DEA's simplicity of use and flexibility in data requirement, it has become a popular tool [12]. In his study, Mostafa [15] explained that the DEA technique is an adequate tool for benchmarking, since it allows the identification of a group of efficient DMUs for each non-efficient one [15]. Furthermore, Lee and Kim [16] mentioned that the greatest merit of DEA is that it provides benchmarking guidelines for inefficient DMUs. For each inefficient DMU, DEA identifies a set of efficiency units called the reference set, which constitutes DEA's benchmark, containing information on the percentage of the efficiency improvement [16]. In their study, Donthu et al.[17] tried to fill the gap in benchmarking marketing productivity via DEA. Gonzales-Padrone et al. [18], proposed a DEA model as a benchmarking tool in order to conduct an efficiency assessment of the sale's staff in dealerships. Mishra [13] utilized DEA in order to assess the relative efficiency of 25 different retail stores in India. Takouda and Dia [19] performed an internal and external benchmarking study, and then compared the technical, pure technical and scale efficiency of three main hardware retail stores in Canada from 2000 to 2010 by using the DEA approach. Similarly, Erdumlu and Saricam [20] applied a DEA model evaluated the technical and scale efficiencies of 30 different apparel retailers in Turkey. Mostafa used a non-parametric DEA approach to measure the relative efficiency of 45 retailers in the USA [15].

*Efficiency in Retail Stores*

Retail productivity is an important issue and an extensive amount of research has been published on this topic. A review of this literature indicates that multiple methodologies have been applied to assess productivity of individual retail stores, groups of stores, and the retail industry[21]. Comparing to manufacturing industries, establishing an appropriate measure of production efficiency is more difficult in service industries, particularly in restaurants[1]. However, the literature survey showed that the use of DEA for evaluating the efficiency of the retailers in different segments of the retailing industry is quite limited.[20] Also, early studies tended to focus on labor productivity because labor expenditures were and continue to be of great importance. More recent studies, however, have examined other factors that may influence store productivity, such as merchandise assortment, location, pricing, and promotion[22]. However, the contemporary research in efficiency measurement suggests that there is an increase in the use of DEA to evaluate retail efficiency and productivity in recent years [23].

*Performance Indicators*

A performance indicator is a frequently used method for measuring the performance of an operating unit. A performance indicator is defined as a ratio of some output to input belonging to the unit being discussed. Performance indicators monitor the individual operations at the franchise/store level, whereas key performance indicators (KPIs) track higher level information at the corporate level. In spite of the generalized acceptance of using a set of KPIs to evaluate corporation's performance, there are a few theoretical and empirical limitations associated with their use. Since an individual indicator only examines a portion of the company activity, a comprehensive performance evaluation must include an analysis of several indicators. Therefore, it may be difficult to gain an overall performance view of a company because of an excessive number of indicators utilized [24].

Companies rely on comparative store efficiency as a key factor in making important strategic management decisions. Store management personnel hiring, promotion and training decisions rely heavily on factors that affect the financial performance of the store. In addition, strategic resource-allocation decisions—such as advertising budgets, store expansions and store closings—are based on company management's understanding of what drives store performance. For instance, if the factors that contribute to low performance are deemed to be unalterable or prohibitively expensive to modify, management may choose to close the store. By adopting a "best practices" approach to continuous improvement and corporate learning, company management continues its ongoing monitoring of overall store operational management procedures and their influence on store performance.[22] Keh and Chu[25] acknowledged that various constructs of output such as sales revenue, physical units, value added, and gross margin, etc. have been proposed and used. However, it is widely recognized that the true output of the retail firm consists of various distribution services. [25] The choice of the input and output variables is vital to the successful application of DEA. It has been stated that input and output variables for DEA should reflect the retail firm's objectives and sales. Previous studies have proposed different measures of output, both in monetary units (such as sales revenue, profit volume and value added) and in non-monetary units (such as customer store loyalty and satisfaction, and service quality) [2, 22, 23, 25].

## 3. Material and Method

The DEA approach has been well studied since Charnes, Cooper and Rhodes [26] first proposed their original DEA model. As Gattoufi et al.[27] demonstrated in their taxonomic review, different DEA models have been applied to evaluate the performance and efficiency of entities in various fields from the finance to retail industries. Liu et al. [28] listed additional major service industries such as banking, health care, agriculture and farm, transportation and education, that DEA models successfully have been employed. DEA models measure the performances of a set of similar entities, aka, Decision Making Units (DMUs), by incorporating multiple input and output factors. In DEA modeling, inputs are considered as the variables that are "smaller is better" in nature and hence are subject to minimization, whereas, outputs are the "larger is better" factors and are subject to maximization. The efficiencies are defined as the ratio of weighted outputs to weighted inputs [29].

The *efficiency* value is a numerical value that defines the efficiency of a system under several inputs and outputs. The DEA approach is selected due to its ability to: [30]

- Deal with specific cases;
- Produce one value for every unit;
- Work with multiple inputs and multiple outputs;
- Not to impose a limitation to the functional relationships between the inputs and outputs;
- Not to require predefined weighing factors for different types of inputs and outputs;
- Focus on the best applications rather than the average of the empirical values; and
- Provide information regarding the requirements for an inefficient unit to become efficient.

DEA can be compared to two commonly used performance evaluation methods: regression analysis and benchmarking. However, the technique distinguishes itself from both with its ability to provide a quantitative evaluation score for each entity without seeking a meaningful relationship among the provided criteria. DEA algorithms can be classified into two categories according to the "orientation" of the model: The first category is called the *Input-oriented DEA model* which concentrates on reducing the amount of input by keeping the output constant. The second category is referred as the *Output-oriented DEA model* which focuses on maximizing the amount of output with the constant amount of input[31].

Additionally, another classification of DEA models emerges depending on the "optimality scale" criterion. Here, DEA models can operate under the assumption of the following factors: Constant Returns to Scale (CRS), or Non-Constant Returns to Scale, i.e., Increasing Returns to Scale (IRS), Decreasing Returns to Scale (DRS), and Variable Returns to Scale32 (VRS) which implies that not all DMUs are functioning at an optimality scale. Regardless of the orientation of the DEA model, viz., input- or output-oriented, CRS is accepted when increasing the number of inputs leads to an equivalent increase in the output. Given that the focus of this paper is on increasing the productivity of each store, output-oriented CRS DEA model is utilized. The following provides further explanation regarding the proposed model.

A basic DEA model allows for the introduction of multiple inputs and multiple outputs by obtaining an "efficiency score" of each DMU with the conventional output/input ratio analysis. Basic efficiency as the ratio of weighted sum of outputs to the weighted sum of inputs. The relative efficiency score of a test DMU *p* can be obtained by solving the following DEA ratio model (CCR) proposed by Charnes, *et al*.[33]:

$$\begin{aligned} max \quad & \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \\ s.\ t. \quad & \frac{\sum_{k=1}^{s} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \le 1 && \forall \text{ DMUs } i \\ & v_k, u_j \ge 0 && \forall\ k, j. \end{aligned} \tag{1}$$

Where,
$k$ = 1 to $s$,
$j$ = 1 to $m$,
$i$ = 1 to $n$,
$y_{ki}$ = amount of output $k$ produced by DMU $i$,
$x_{ji}$ = amount of input $j$ produced by DMU $i$,
$v_k$ = weight given to output $k$,
$u_j$ = weight given to input $j$.

Equation (1) can be converted into a linear program as shown in Equation (2). We refer the reader to the study by Charnes *et al*.[34] for further explanation of the model.

$$max \quad \sum_{k=1}^{s} v_k y_{kp} \tag{2}$$

$$
\begin{aligned}
s.\,t. \quad & \sum_{j=1}^{m} u_j x_{jp} = 1 & \\
& \sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \leq 0 & \forall \text{ DMUs } i \\
& v_k, u_j \geq 0 & \forall\ k, j,
\end{aligned}
$$

where, the $\sum_{j=1}^{m} u_j x_{jp} = 1$ constraint sets of an upper bound of 1 for the relative efficiency score.

In the CCR model provided in Equation (2), evaluating the efficiency of *n* DMUs that correspond to a set of *n* Linear Programming (LP) problems. Using duality, the dual of the CRS model can be represented as illustrated in Equation (3):

$$
\begin{aligned}
min \quad & \theta & \\
s.t. \quad & & \\
& \sum_{i=1}^{n} \lambda_i x_{ji} - \theta x_{jp} \leq 0 & \forall \text{ Inputs } j \\
& \sum_{i=1}^{n} \lambda_i y_{ki} - y_{kp} \geq 0 & \forall \text{ Outputs } k \\
& \lambda_i \geq 0 & \forall \text{ DMUs } i.
\end{aligned} \tag{3}
$$

Equation 3 represents the duality of the basic input-oriented CCR model assuming “constant returns to scale” for all the inputs and outputs. Using Talluri’s [35] notation, the duality of a basic output-oriented CRS model can be written as follows:

$$
\begin{aligned}
max \quad & \phi & \\
s.t. \quad & & \\
& x_{jp} - \sum_{i} \lambda_i x_{ji} \geq 0 & \forall \text{ Inputs } j \\
& -\phi y_{kp} + \sum_{i} \lambda_i y_{ki} \geq 0 & \forall \text{ Outputs } k \\
& \lambda_i \geq 0 & \forall \text{ DMUs } i.
\end{aligned} \tag{4}
$$

In the case where not all of the DMUs are functioning at an optimality scale, Equation 4 could be converted into a VRS model by including the constraint $\sum_i \lambda_i \geq 0$ to the set of technological constraints.

The result of Equation 4, $\Phi$ is the relative efficiency score of each DMU. Inverse of the variable $\Phi$ ($1/\Phi$) provides the technical efficiency value (*TE*) for each DMU. Here, given the technical efficiency value is equal to one ($TE = 1$), DMU $p$ is considered efficient for its selected weights. Hence, DMU $p$ lies on the optimal frontier, and is not dominated by any other DMU. Comparatively, if the technical efficiency value is less than one ($TE < 1$), then DMU $p$ is not on the optimal frontier and the existence of at least one efficient DMU is present in the population.

The following demonstrates the collected data and the application of the CRS DEA model as applied to the relative efficiency evaluation process of the retail stores.

## 4. The Problem Description and the Case Study

### 4.1. The Data Collection

In order to evaluate the efficiency of 20 franchise retail stores, the data was collected from the franchise that operates in Massachusetts and New Hampshire. The analysis was conducted in a homogenous sample. In order to comply with assured confidentiality agreements with the franchisee, the identity of the name of the business and the restaurant chain is undisclosed. In the proposed study, the research instruments used are interviews and brain-storming methods with the franchisee and supervisors in order to identify the performance indicators. These indicators will be used as the input and output criteria in the model. Table 1 demonstrates the input and output criteria. Compatible with the DEA rules, the variables that are subject to minimization, viz., total numbers of carry-out and delivery orders, sales, and the percentages of on time delivery and out-to-door time, are accepted as output; whereas, the remaining criteria, viz., store territory, population density, weekly expenses, total hours of work by delivery and store personnel are accepted as input criteria. Since there is a major difference between weekday and weekends operations, only weekly operation data is considered in the study.

Table 1. Input and Output Criteria for the DEA Model

| Input Criteria (per week) | Unit | Output Criteria (per week) | Unit |
|---|---|---|---|
| Store Territory | Sq. Mile | Total Number of Carry-out Orders | Number of Orders /week |
| Population Density | Population/Sq Mile | Total Number of Delivery Orders | Number of Orders /week |
| Weekly Expenses | Dollars /week | Sales | Dollars /week |
| Total hours worked by in-store personnel | Hours /week | % Delivery On Time | Percentage |
| Total hours worked by delivery personnel | Hours /week | % Out to Door Time | Percentage |

Table 2 and Table 3 values reflect the averages of weekly data collected for a 3-month period for each of store. The demographic data, population density and territory data, are retrieved from USA Census 2010 results[36, 37] .

Table 2. Input Data for the DEA Model

| INPUT | | | | | |
|---|---|---|---|---|---|
| Area | Store Territory (Sq. Mile) | Population Density (Population/ Sq. Mile) | Weekly Expenses (Dollars/Week) | Total hours worked by in-store personnel (Hours/Week) | Total hours worked by delivery personnel (Hours/Week) |
| Allston, MA | 4.3 | 26216.44 | 17799 | 397 | 702 |
| Bedford, MA | 14.5 | 2730.03 | 6356 | 149 | 243 |
| Brighton, MA | 3.6 | 16235.29 | 10596 | 291 | 304 |
| Canton, MA | 18.8 | 1147.04 | 6318 | 204 | 332 |
| Charlestown, MA | 1.4 | 12159.02 | 7653 | 128 | 199 |
| Derry,NH | 36.0 | 924.50 | 8663 | 191 | 292 |
| Downtown Boston, MA | 1.3 | 182169.49 | 15859 | 266 | 590 |
| Eastbridgewater, MA | 17.2 | 801.56 | 9459 | 216 | 325 |
| Fenway, MA | 2.7 | 115685.15 | 26317 | 477 | 822 |
| Holbrook, MA | 7.0 | 1533.47 | 9354 | 162 | 315 |
| Newton, MA | 14.1 | 35240.71 | 9183 | 236 | 357 |
| North Brockton, MA | 12.4 | 4907.91 | 9755 | 203 | 368 |
| North Quincy, MA | 4.5 | 16586.98 | 9471 | 141 | 248 |
| Reading, MA | 14.9 | 2411.03 | 8141 | 163 | 294 |
| Roslindale, MA | 3.6 | 11506.94 | 7179 | 140 | 266 |
| Roxbury, MA | 5.1 | 79371.24 | 21566 | 398 | 729 |
| Salem, NH | 24.7 | 1163.84 | 7740 | 148 | 240 |
| South Brockton, MA | 8.9 | 3682.90 | 9280 | 188 | 294 |
| South Quincy, MA | 9.0 | 6137.00 | 13686 | 226 | 428 |

Table 3. Output Data for the DEA Model

| OUTPUT | | | | | |
|---|---|---|---|---|---|
| Area | Total Number of Carry-out Orders (Number of Orders/Week) | Total Number of Delivery Orders (Number of Orders/Week) | Sales (Dollars/Week) | % Delivery On Time (Percentage) | % Out to Door Time (Percentage) |
| Allston, MA | 201 | 781 | 30640 | 53% | 55% |
| Bedford, MA | 167 | 286 | 9940 | 52% | 58% |
| Brighton, MA | 254 | 762 | 22369 | 74% | 85% |
| Canton, MA | 168 | 255 | 8055 | 55% | 53% |
| Charlestown, MA | 173 | 332 | 12716 | 83% | 79% |
| Derry,NH | 359 | 230 | 10330 | 51% | 57% |
| Downtown Boston, MA | 324 | 1240 | 33760 | 87% | 83% |
| Eastbridgewater, MA | 381 | 507 | 13344 | 56% | 62% |
| Fenway, MA | 458 | 2187 | 60236 | 83% | 63% |
| Holbrook, MA | 461 | 423 | 11156 | 86% | 87% |
| Newton, MA | 173 | 378 | 10295 | 53% | 69% |
| North Brockton, MA | 418 | 476 | 16230 | 52% | 83% |
| North Quincy, MA | 304 | 508 | 15644 | 58% | 52% |
| Reading, MA | 235 | 348 | 10924 | 58% | 66% |
| Roslindale, MA | 253 | 381 | 11141 | 54% | 78% |
| Roxbury, MA | 644 | 1632 | 43344 | 41% | 50% |
| Salem, NH | 261 | 269 | 10309 | 56% | 67% |
| South Brockton, MA | 343 | 533 | 15222 | 71% | 88% |
| South Quincy, MA | 359 | 566 | 17826 | 49% | 67% |
| West Roxbury, MA | 298 | 398 | 18292 | 73% | 82% |

## 4.2. Analysis and Results

Using the data shown in Table 2 and Table 3, the input-oriented DEA model was utilized for each store using MaxDEA[38]. After the runs are completed for all of the 20 stores, the technical efficiency (TE) is calculated as a reciprocal of each model outcome (TE = $1/\Phi$) for each store. The results of the model are presented in Table 4:

Table 4. The DMU Scores

| NO | DMU | Score |
|---|---|---|
| 3 | Brighton | 1.000 |
| 5 | Charlestown | 1.000 |
| 7 | Downtown Boston | 1.000 |
| 8 | Eastbridgewater | 1.000 |
| 9 | Fenway | 1.000 |
| 10 | Holbrook | 1.000 |
| 13 | North Quincy | 1.000 |
| 15 | Roslindale | 1.000 |
| 16 | Roxbury | 1.000 |
| 17 | Salem | 1.000 |
| 18 | South Brockton | 1.000 |
| 20 | West Roxbury | 1.000 |
| 6 | Derry | 0.977 |
| 12 | North Brockton | 0.969 |
| 1 | Allston | 0.963 |
| 4 | Canton | 0.956 |
| 2 | Bedford | 0.904 |
| 19 | South Quincy | 0.896 |
| 14 | Reading | 0.852 |
| 11 | Newton | 0.723 |
| **Average** | | **0.962** |

The graphical representation of the results is provided in Figure 1.

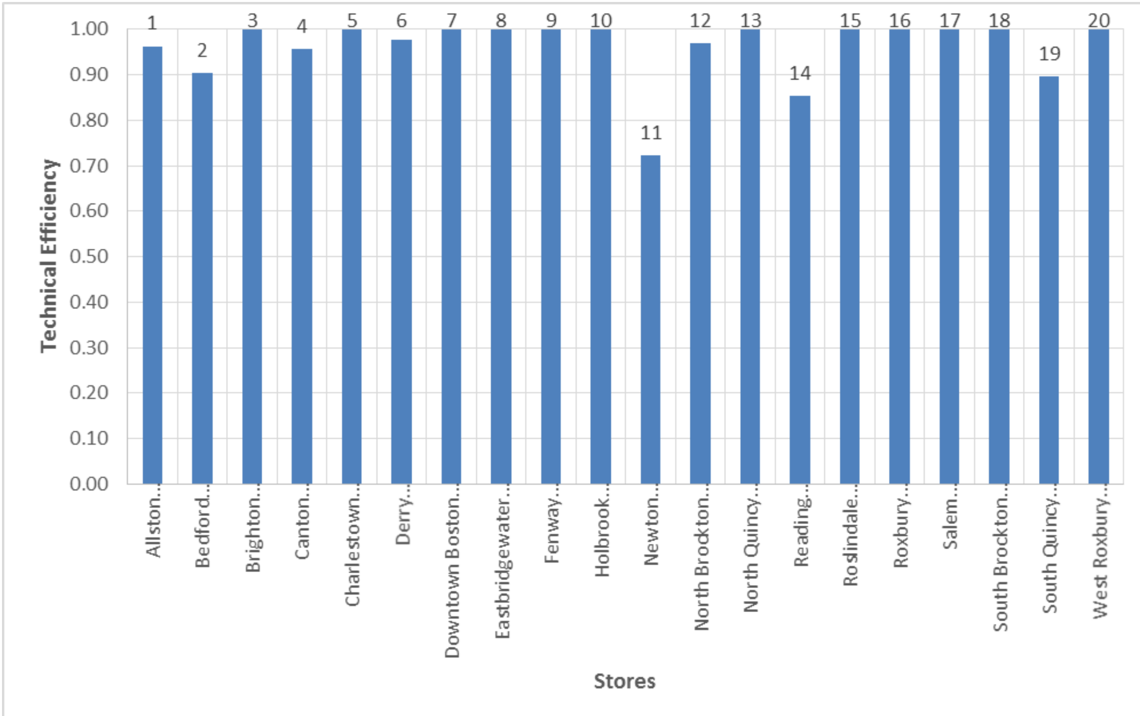


Figure 1. Performance Efficiencies of 20 Stores According to the DEA Model Results

As seen in Table 3 and Figure 1, the average efficiency score is 96.2% and the lowest score belongs to Newton, MA store. This is followed by Reading, South Quincy, Bedford and Canton, respectively. Further analyses of the data shows that, even though they have higher costs and serving to smaller areas, 12 out of 20 stores are efficient with corresponding technical efficiency score of 1. The population density and the size of the territory seem to have a significant impact on both in-store and delivery performance.

## 5. Conclusions and Future Research

In this study, an implementation of an input-oriented DEA model is considered and applied to a sample of 20 franchise stores operating Massachusetts and New Hampshire to determine the relative efficiency score.

The paper contributes to the DEA related literature by introducing additional criteria for store performance evaluation given that majority of the retail performance studies heavily rely on labor productivity. In addition, the research aims at contributing to the retail store performance evaluation field where there is substantial need for quantitative analysis as evidenced by the literature review.

The model provides a basis to conduct a fast and reliable automated application evaluation process. Therefore, management in the franchise business should consider the DEA method as a useful analytical and diagnostic tool to improve efficiency. They should evaluate the applicability and convenience of DEA for the store operations as a benchmarking tool and DEA's potential to achieve the desired level of performance.

Since DEA is a data dependent technique, the accuracy of the model results are highly correlated with the quality of the data inputted to the model. However, in many cases the input and output data could not always be measured and/or collected accurately due to increased variety of data providers and/or subjective nature of the data. In the future, we plan to apply the fuzzy set theory into the model to overcome this shortcoming.

## References

1 Choi, K.W., Roh , Y.S., and Yoon, J.-H.: 'AN EMPIRICAL EXAMINATION OF PRODUCTIVITY OF A CHAIN RESTAURANT USING DATA ENVELOPMENT ANALYSIS (DEA)', International Journal of Quality and Productivity Management, 2007, 07, (01), pp. 47-67

2 Donthu, N., and Yoo, B.: 'Retail productivity assessment using data envelopment analysis', Journal of Retailing, 1998, 74, (1), pp. 89-105

3 Kao, L.-J., Lu, C.-J., and Chiu, C.-C.: 'Efficiency measurement using independent component analysis and data envelopment analysis', European Journal of Operational Research, 2011, 210, (2), pp. 310-317

4 Dotoli, M., Epicoco, N., Falagario, M., and Sciancalepore, F.: 'A cross-efficiency fuzzy Data Envelopment Analysis technique for performance evaluation of Decision Making Units under uncertainty', Computers & Industrial Engineering, 2015, 79, (0), pp. 103-114

5 Samoilenko, S., and Osei-Bryson, K.-M.: 'Using Data Envelopment Analysis (DEA) for monitoring efficiency-based performance of productivity-driven organizations: Design and implementation of a decision support system', Omega, 2013, 41, (1), pp. 131-142

6 Ismail, Z., Tai, J.C., Kong, K.K., Law, K.H., Shirazi, S.M., and Karim, R.: 'Using data envelopment analysis in comparing the environmental performance and technical efficiency of selected companies in their global petroleum operations', Measurement, 2013, 46, (9), pp. 3401-3413

7 Farrel, M.J.: 'The Measurement of Productive Efficiency ', J. Roy. Stat. Soc., (1957), 120 ((3)), pp. 253–281

8 Müller, J.: 'Efficiency vectors, efficiency and performance measures: new methods for ranking efficient organizational units', Journal of Productivity Analysis, 2008, 30, (2), pp. 99-106

9 Pareto, V.: 'Cours de´conomic politique, Lausanne', vol 2

10 Koopmans , T.: 'Analysis of production as an efficient combination of activities. In: Koopmans TC (ed) Activity analysis of production and allocation.', Wiley, New York, 1951, pp. 33–97

11 Yadav, V.K., Padhy, N.P., and Gupta, H.O.: 'Performance evaluation and improvement directions for an Indian electric utility', Energy Policy, 2011, 39, (11), pp. 7112-7120

12 Lau, K.H.: 'Measuring distribution efficiency of a retail network through data envelopment analysis', International Journal of Production Economics, 2013, 146, (2), pp. 598-611

13 Mishra, R.K.: 'Benchmarking Scheme for Retail Stores Efficiency', International Journal of Marketing Studies, 2009, 1, (2), pp. 131-150

14 Paradi, J.C., and Zhu, H.: 'A survey on bank branch efficiency and performance research with data envelopment analysis', Omega, 2013, 41, (1), pp. 61-79

15 Mostafa, M.M.: 'Benchmarking the US specialty retailers and food consumer stores using data envelopment analysis', International Journal of Retail & Distribution Management, 2009, 37, (8), pp. 661-679

16 Lee, H., and Kim, C.: 'Benchmarking of service quality with data envelopment analysis', Expert Systems with Applications, 2014, 41, (8), pp. 3761-3768

17 Donthu, N., Hershberger, E.K., and Osmonbekov, T.: 'Benchmarking marketing productivity using data envelopment analysis', Journal of Business Research, 2005, 58, (11), pp. 1474-1482
18 Gonzalez-Padron, T., Akdeniz, M.B., and Calantone, R.J.: 'Benchmarking sales staffing efficiency in dealerships using extended data envelopment analysis', Journal of Business Research, 2014, 67, (9), pp. 1904-1911
19 Takouda, P.M., and Dia, M.: 'Benchmarking chains of hardware retail stores in Canada', in Editor (Ed.)^(Eds.): 'Book Benchmarking chains of hardware retail stores in Canada' (2013, edn.), pp. 1-6
20 Erdumlu, N., and Sariçam, C.: 'Measuring the Efficiency of Turkish Apparel Retailers/Türk Hazir Giyim Perakendecilerinin Etkinliklerinin Ölçümü', Ege Akademik Bakis, 2013, 13, (2), pp. 237-244
21 Kamakura, W.A., Lenartowicz, T., and Ratchford, B.T.: 'Productivity assessment of multiple retail outlets', Journal of Retailing, 1996, 72, (4), pp. 333-356
22 Thomas, R.R., Barr, R.S., Cron, W.L., and Slocum Jr, J.W.: 'A process for evaluating retail store efficiency: a restricted DEA approach', International Journal of Research in Marketing, 1998, 15, (5), pp. 487-503
23 Yu, W., and Ramanathan, R.: 'An assessment of operational efficiency of retail firms in China', Journal of Retailing and Consumer Services, 2009, 16, (2), pp. 109-122
24 Horta, I.M., Camanho, A.S., and Moreira da Costa, J.: 'Performance assessment of construction companies: A study of factors promoting financial soundness and innovation in the industry', International Journal of Production Economics, 2012, 137, (1), pp. 84-93
25 Keh, H.T., and Chu, S.: 'Retail productivity and scale economies at the firm level: a DEA approach', Omega, 2003, 31, (2), pp. 75-82
26 Charnes, A., W. Cooper, and E. Rhodes,: ' Measuring the Efficiency of Decision-Making Units. ', European Journal of Operational Research, 1978, 2(6), pp. 429–444.
27 Gattoufi, S., Oral, M., and Reisman, A.: 'A taxonomy for data envelopment analysis', Socio-Economic Planning Sciences, 2004, 38, (2–3), pp. 141-158
28 Liu, J.S., Lu, L.Y.Y., Lu, W.-M., and Lin, B.J.Y.: 'A survey of DEA applications', Omega, 2013, 41, (5), pp. 893-902
29 Sarkis, J., and Talluri, S.: 'Efficiency measurement of hospitals: Issues and extensions', International Journal of Operations & Production Management, 2002, 22, (3), pp. 306-313
30 Madu, C.N., and Kuei, C.H.: 'Application of data envelop analysis in benchmarking', International Journal of Quality Science, 1998, 3, (4), pp. 320-327
31 Kongar, E., Pallis, J.M., and Sobh, T.M.: 'A Non-parametric Approach for Evaluating the Performance of Engineering Schools', International Journal of Engineering Education, 2010, 26, (5)
32 Banker, R.D., Charnes, A., and Cooper, W.W.: 'Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis', Management Science, 1984, 30, (9), pp. 1078-1092
33 Charnes, A., Cooper, W., and Rhodes, E.: 'Measuring the Efficiency of Decision-Making Units', European Journal of Operational Research, 1978, 2, (6), pp. 429–444
34 Charnes, A., Cooper, W.W., Lewin, A.Y., and Seiford, L.M.: 'Data Envelopment Analysis: Theory, Methodology, and Applications' (Kluwer, 1994. 1994)
35 Talluri, S.: 'Data Envelopment Analysis: Models and Extensions', *Decision Line*, 2000, 31, (3), pp. 8-11
36 http://www.census.gov/2010census
37 http://www.unitedstateszipcodes.org
38 http://www.maxdea.cn/MaxDEA.htm

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# Numerical Simulation of the Dynamics of Water Droplet Impingement on a Wax Surface

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## Abstract

The impact of droplets on solid surfaces is important for a wide range of engineering applications, such as ink-jet printing, spray cooling of hot surfaces, spray coating and painting, solder-drop deposition, blood spattering for criminal forensics and disease detection, etc. This paper simulated the dynamic process of a water droplet impinging onto a wax substrate in COMSOL, using the Phase Field method for tracking the free surface. The predicted spreading factor and apex height were validated against experimental results, showing good agreement during the dynamic impingement process. The effect of contact angles on the impingement process was also studied. The initial inertia driven spreading process is not affected by the contact angle, but the later spreading process and recoil process are significantly affected by the contact angle. The simulation results can provide a good understanding of the dynamic impingement process and provide insights on how surface wettability can affect the droplet spreading and rebounding process.

## Keywords

Droplet impingement, two phase flow, hydrophobic surface, phase field method, contact angle

## Introduction

The dynamic behavior of droplet impingement on a solid surface is important to many engineering applications, such as rain drops on automobile windshields, inkjet deposition and metal deposition in manufacturing processes, spray cooling of electronics, and spray coating for various applications. The droplet can spread, splash, and rebound after hitting a solid surface. The resulting phenomena and the final shape of the droplet on a surface depend on several parameters, including the properties of the droplet and the impacted surface, the droplet impact velocity, the droplet size, the angle of attack to the surface, the droplet physical properties, the surface wettability, and surrounding pressure[1]. Impacts of a droplet onto a solid surface are controlled by three key factors: inertia, viscous dissipation and interfacial energy[2,3]. The impact phenomena is characterized by dimensionless numbers[2,3], such as the Weber number ($We = \rho V_i^2 D_0/\sigma$), the Reynolds number ($\mathrm{Re} = \rho V_i D_0/\mu$), the Ohnesorge number ($Oh = (We)^{1/2}/Re$), and the Capillary number ($Ca = We/Re$), where $\rho$ is the fluid density, $\mu$ is the fluid dynamic viscosity, $\sigma$ is the surface tension, $D_0$ is the droplet initial diameter, and $V_i$ is the impact velocity.

Significant research has been dedicated to the study of droplet impingement under various conditions, experimentally, numerically, and analytically[4,5]. Sikalo and Ganic[4] and Sikalo et al.[5] conducted experiments to study the droplet impact of three different fluids on surfaces with various conditions, including dry and wet, smooth and rough, hydrophilic and hydrophobic, and horizontal and inclined. Rein[6], Yarin[7], and Marengo et al.[8] provided comprehensive reviews of droplet impact phenomena under various impacting conditions.

Numerical simulations of droplet impact process can provide insights for the underlying flow physics. Numerical modeling of droplet impact process involves three complexities[9]: (1) tracking the droplet-ambient fluid interface that undergoes extreme deformation in a short time and accounting for the surface tension, (2) resolving the three-phase contact line singularity, and (3) incorporating effects of the surface wettability. Several numerical models were used for interface tracking, including volume of fluid (VOF) method[10,11], Level Set (LS) method[12,13], coupled LS-VOF method (CLSVOF)[14,15], Boundary Element method (BEM)[16], Lattice-Boltzman method (LBM)[17,18], and Phase Field method[19-21]. One of most challenging tasks is to correctly predict the gas–liquid interaction on a three-phase contact line while simultaneously trying to avoid numerical diffusion[10]. Most models apply a contact angle as a boundary condition at the active boundary cells at the wall[10].

Contact angle hysteresis, a difference between the advancing contact angle and receding contact angle, is observed experimentally during the droplet spreading and recoiling process. This dynamic variation of contact angle during the spreading process might be caused by surface inhomogeneity, surface roughness, impurities on the surface and temperature variation[19]. When prescribing the contact angle, the value of the angle is dependent on the sign of the contact-line speed $U_{CL}$ because of hysteresis[22,23]. As it is normally difficult to incorporate a dynamically varying contact angle in computations, a constant contact angle has typically been used. Several works have been devoted to predict the dynamic change of contact angle during the droplet impact process in order to capture the temporal evolution of the phenomenon[10,15,21-24].

The dynamic process of droplet impingement is complex and the mechanism of droplet and surface interaction is not fully understood. This paper investigates the dynamic behavior of a droplet impinging onto a dry wax surface using COMSOL with the Phase Field method. Two different fixed contact angles as well as contact angle hysteresis are studied to see their effects on the droplet impingement process.

## Mathematical Model

Assuming that both liquid and gas are Newtonian and the flow is laminar, the flow field can be obtained by solving the Navier-Stokes equations, while the free surface between the two fluids is tracked by the Phase Field method.

The Navier-Stokes equations for the conservation of mass and momentum are formulated as follows:

$$\nabla \mathbf{u} = 0$$

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\nabla\mathbf{u}\right) = \nabla\left[-p\mathbf{I} + \mu\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right] + \rho\mathbf{g} + \mathbf{F}_{st}$$

where $\rho$ is the fluid density, **u** is the velocity vector, $\mu$ is the fluid dynamic viscosity, $t$ is time, $p$ is fluid pressure, **g** is the gravitational acceleration, $\mathbf{F}_{st}$ (defined below) is the surface tension force, and **I** is the identity matrix.

The Phase Field method is based on the Cahn-Hilliard equation[25], tracking a diffuse surface separating the immiscible phases. The interface is defined by a dimensionless number ($\phi$) that varies from -1 to 1. The 4th order Cahn-Hilliard equation is decomposed into two 2nd order partial differential equations:

$$\frac{\partial \phi}{\partial t} + \mathbf{u}\nabla\phi = \nabla \cdot \frac{\gamma\lambda}{\varepsilon^2}\nabla\psi$$

$$\psi = -\nabla \cdot \varepsilon^2 \nabla\phi - (\phi^2 - 1)\phi$$

where $\gamma$ is the mobility, $\lambda$ is the mixing energy density and $\varepsilon$ is the interface thickness parameter. The mixing energy density and the interface thickness are related to the surface tension coefficient, $\sigma$, through the following relation:

$$\sigma = \frac{2\sqrt{2}\lambda}{3\varepsilon}$$

The mobility determines the time scale of the Cahn-Hilliard diffusion and must be large enough to retain a constant interfacial thickness but small enough so that the convective terms are not overly damped. In COMSOL the mobility is determined by a mobility tuning parameter ( $\chi$ ) that is a function of the interface thickness, $\gamma = \chi\varepsilon^2$. The interfacial thickness is usually taken as the half of the typical mesh size in the region passed by the interface.

The surface tension force is computed as

$$\mathbf{F}_{st} = G\nabla\phi$$

where G is the chemical potential calculated as

$$G = \frac{\lambda}{\varepsilon^2}\psi$$

The volume fractions of the fluids are calculated by

$$V_{fa} = \frac{1-\phi}{2} \quad \text{and} \quad V_{fl} = \frac{1+\phi}{2}$$

The density and viscosity are defined by to vary smoothly across the interface through the definitions

$$\rho = \rho_a + (\rho_l - \rho_a)V_{fl}$$

$$\mu = \mu_a + (\mu_l - \mu_a)V_{fl}$$

where $\rho_a$, $\rho_l$, and $\mu_a$, $\mu_l$ are the densities and dynamic viscosities of the air and liquid, respectively.

## Numerical model

An axisymmetric numerical model is implemented in the commercial finite element software COMSOL 4.3b. The geometry is shown in Fig. 1, where the water droplet is initially positioned at a certain distance above the substrate with an initial velocity. The droplet travels downward toward the substrate under the influence the gravity force and reaches the substrate at an impact velocity $V_i$.

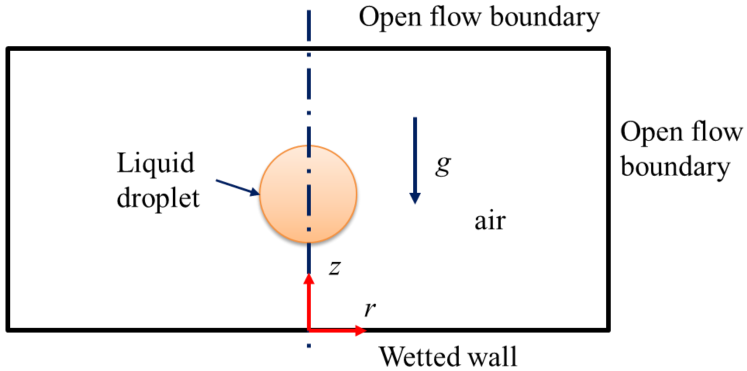


**Figure 1.** Schematic of axisymmetric computational domain

Open boundary conditions are used at the top and side to simulate an infinite domain. A wetted wall boundary condition is used for the substrate at the bottom. It sets the mass flow across the wall to be zero and specify the contact angle $\theta_w$ of fluid at the wall. This is prescribed by

$$\mathbf{n}\cdot\varepsilon^2\nabla\phi = \varepsilon^2\cos(\theta_w)\left|\nabla\phi\right|$$

$$\mathbf{n}\cdot\frac{\sigma\lambda}{\varepsilon^2}\nabla\psi = 0$$

As shown in Figure 2, contact angle $\theta$ affects the droplet wet diameter $d$ and height $h$ during the droplet spreading process. The spreading factor ($d/D_0$) is the dimensionless wet diameter at the contact, and the apex height ($h/D_0$) is the dimensionless droplet height at the centerline, both normalized by the droplet initial diameter $D_0$.

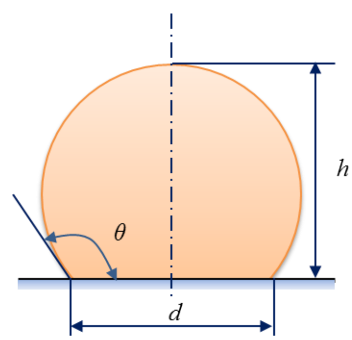


**Figure 2.** Schematic of droplet attached to a surface: $\theta$, contact angle; $h$, droplet height; $d$, droplet wet diameter

## Results and Discussion

The paper studied a water droplet of diameter 2.7 mm impinging onto a solid wax surface with an impacting velocity of 1.55 m/s. The material properties of the water droplet and air are listed in Table 1. The Reynolds number, Weber number, Capillary number and Ohnesorge number are calculated to be Re = 4200, We = 89, Ca = 0.021, and Oh = 0.0023, respectively. According to Shiaffino and Sonin[20,26], the droplet impact behavior in this study is in the regime of hydrodynamic pressure-controlled flow.

The surface wettability of water on a wax surface was characterized by Sikalo and Ganic[4] and Sikalo et al.[5] with static advancing contact angle ($\theta_a$ = 105°) and static receding contact angle ($\theta_r$ = 95°). However, it is difficult to measure the dynamic contact angles. Therefore, contact angles are varied in the simulation to study their effects on the impingement process. Three different settings of contact angles are used: (1) fixed advancing contact angle ($\theta_a$ = 105°) and fixed receding contact angle ($\theta_r$ = 95°), and (2)-(3) fixed contact angles ($\theta$ = 95° and 100°) unaffected by motion.

**Table 1.** The properties of water and air

| Parameter | Density | Viscosity | Surface tension |
|---|---|---|---|
| | $\rho$, kg/m$^3$ | $\mu$, Pa·s | $\sigma$, N/m |
| Water | 998 | 0.001 | 0.073 |
| Air | 1.204 | 1.814×10$^{-5}$ | |

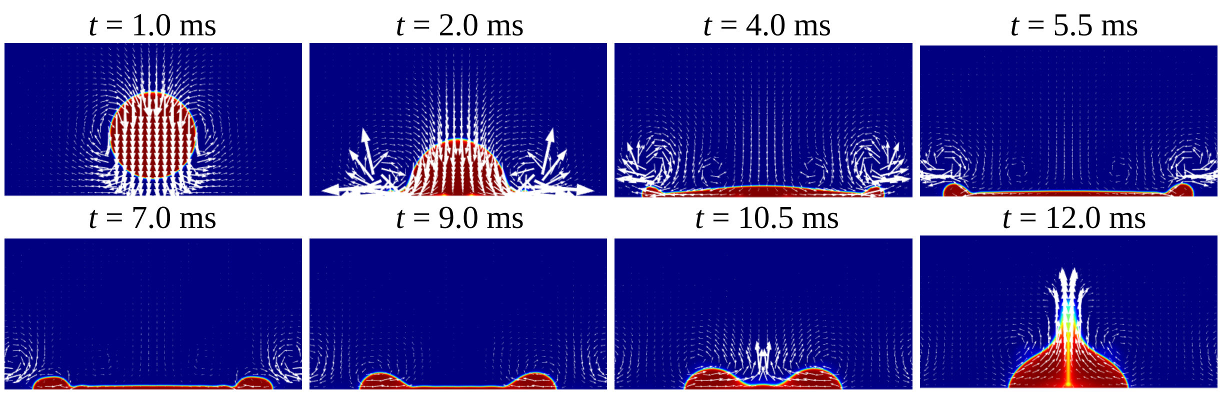


**Figure 3.** Time sequence of water droplet spreading and initial recoiling obtained with an advancing angle ($\theta_a$) of 105° and a receding angle of ($\theta_r$) of 95°.

Figures 3 and 4 show an evolving sequence of droplet shapes at various time instants simulated with an advancing angle ($\theta_a$) of 105° and a receding angle of ($\theta_a$) of 95°. Velocity vectors are overlaid on the droplet volume fraction contours. It can be seen that the spreading process is driven by the impact pressure and resisted by inertia, and a ring forms at the droplet periphery. The spreading decelerates under the resistance of viscous and capillary forces. Some of the impact energy is dissipated through viscous friction and most of it is stored as surface energy. The droplet reaches its maximum spreading radius around 5.5ms and starts to recoil under the influence of hydrostatic force and capillary force. The central liquid film continues to become thinner, but is still connected to the ring during the spreading and recoiling process. Driven by the capillary force, the ring then begins to move toward the center and contact surface decreases. The ring fluid collides at the center at around 11ms resulting in a large pressure and the liquid starts to move upward. The liquid-solid contact area continues to decrease while the liquid column moves upward and the apex height reaches its maximum at 16.8 ms. The small droplet formed by the fast moving liquid at the top is pulled back into the main liquid column by surface tension, resulting in a temporary setback of the apex height. The fast moving liquid at the top forms another droplet and the liquid continues to move up to the point where the kinetic energy is largely converted to surface energy. The unstable liquid column then starts to move downward and breaks up at 38.8ms leaving a small amount of liquid behind. The partially rebounded droplet re-contacts the substrate at 40.0ms and combines with the small amount of remnant liquid left at the surface.

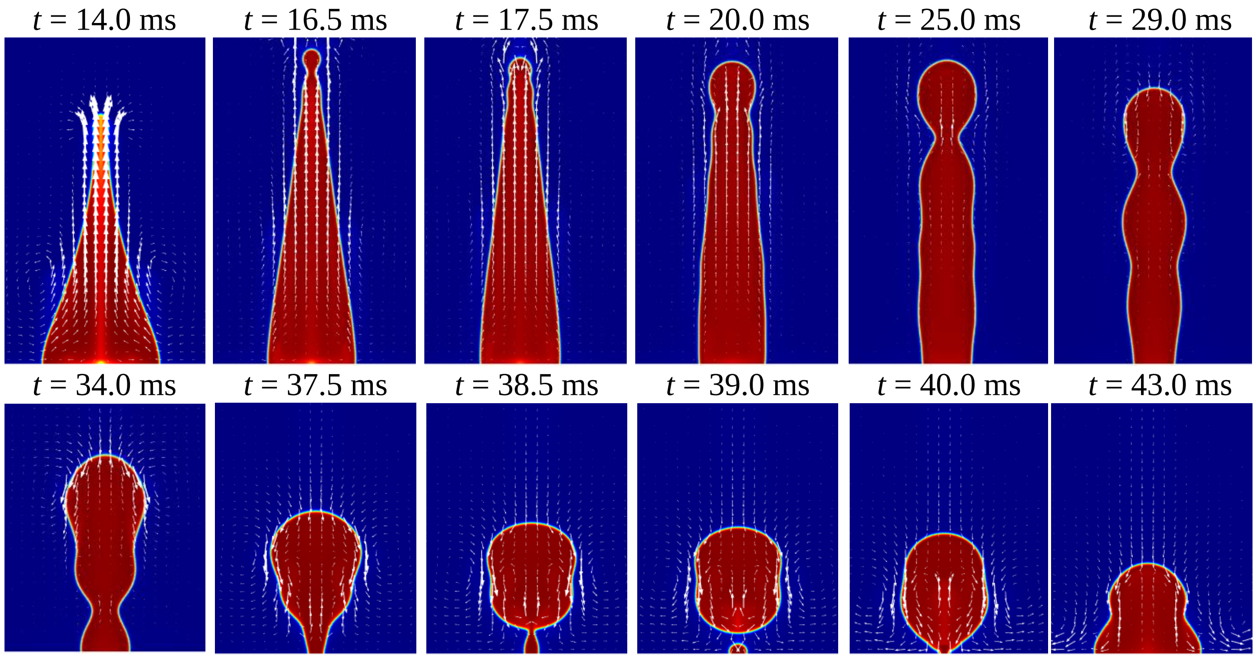


**Figure 4.** Time sequence of water droplet recoiling process water obtained with an advancing angle ($\theta_a$) of 105° and a receding angle of ($\theta_r$) of 95°.

The changes of spreading factor and apex height during the impingement process can be seen in Figs. 5 and 6, which plot the simulation results obtained with different contact angle settings against the experimental data of Sikalo and Ganic[4] and Sikalo et al.[5] The early spreading process is not affected by the contact angle settings and agrees with the experimental data very well. However, the contact angle affects the maximum spreading and the recoil process. The smaller contact angle leads to a bigger maximum spreading factor.

Sikalo and Ganic[4] and Sikalo et al.[5] observed a small secondary droplet breaking up at around 21ms and another possible bigger droplet breakup near 33ms. Secondary droplet generation is observed in the simulations as well. The first case simulated with an advancing angle ($\theta_a$) of 105° and a receding angle of ($\theta_r$) of 95° predicted the first droplet oscillation near 29ms and the second droplet breakup near 39ms. While the simulation does not predict the breakup of the first droplet and the time of breakup differs, the simulation results capture the whole process well. As shown in Fig. 4, the rebounding process is highly unstable, so it is difficult to predict the exactly the secondary droplet breakups. The recoiling process is found to be highly dependent on the contact angle. As shown in Fig. 5, the simulation with a 95° constant contact angle predicted the first droplet breakup at 26.5ms and the second droplet rebound at 38.3ms. The first droplet size is small and the downward momentum after the first droplet breakup is not strong enough to hold the remnant fluid on the substrate. A second droplet with almost all of the remnant fluids rebounds for less than 1ms and then returns to the substrate. At a higher contact angle of $100^{o}$ (Fig. 6) the droplet has a complete rebound at 29ms and the rebound droplet breaks into two droplets at 30.5ms. The sequence of droplet shape evolution in the recoiling process for the $90^{o}$ and $100^{o}$ cases can be found in Figs. 7 and 8.

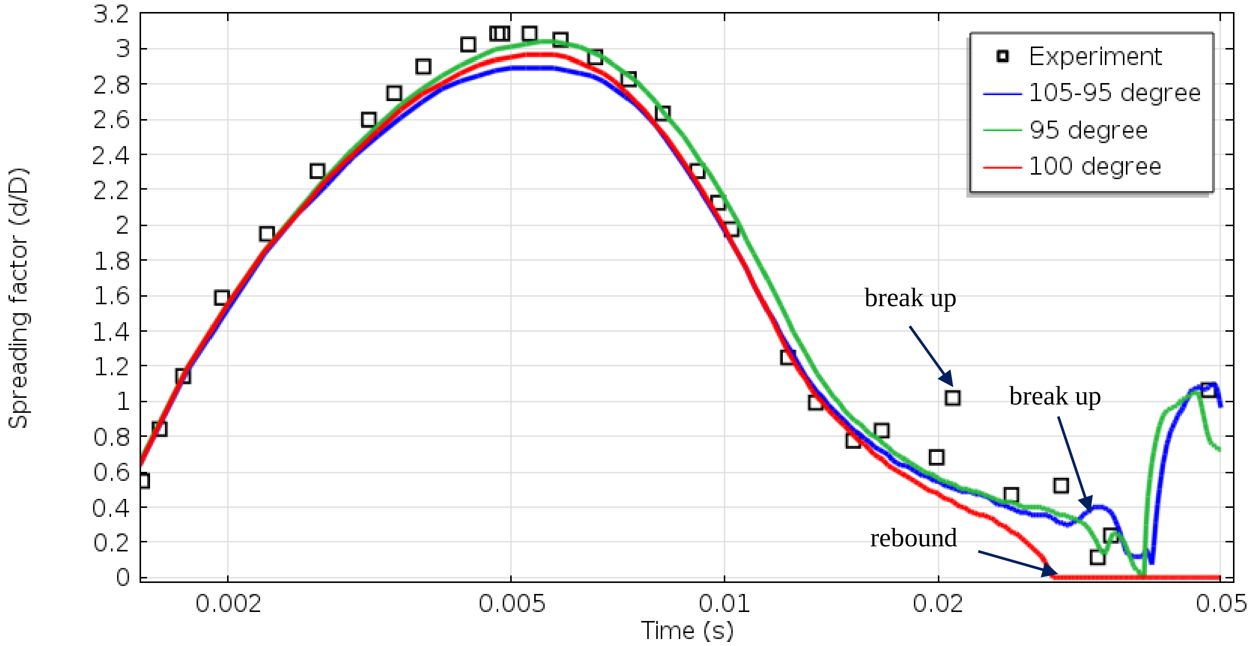


**Figure 5.** Comparison of simulated spreading factors with the experimental data.

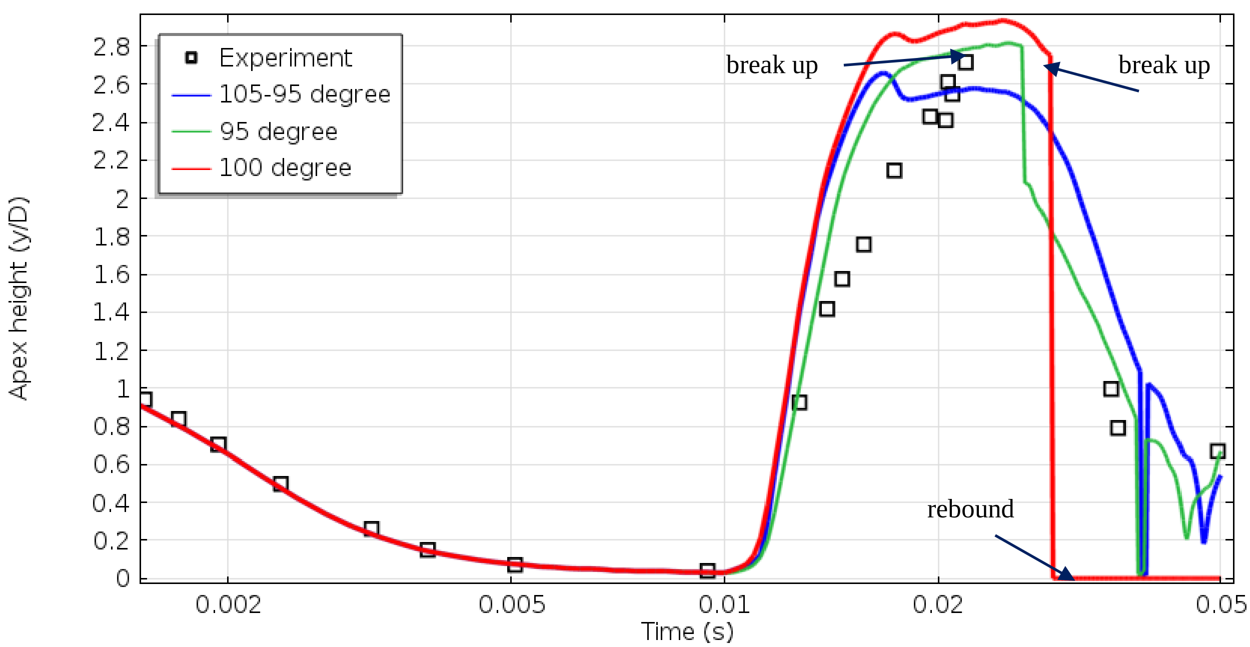


**Figure 6.** Comparison of simulated apex heights with the experimental data.

## Conclusions

This paper simulated the dynamic process of a water droplet impinging onto a wax substrate with the Phase Field method. The dynamic process of droplet evolutions was presented. The predicted spreading factor and apex height were validated against experimental results. The simulation results showed good agreement with the dynamic impingement process found in the experiment. The effect of contact angles on the impingement process was also studied. The initial inertia driven spreading process is not affected by the contact angle, but the later spreading process and recoil process are significantly affected by the contact angle. Higher contact angle during the advance stage lead to a smaller maximum spreading factor and a sooner rebound. The rebound liquid column is unstable with one or two secondary droplet form. The simulation results can provide a good understanding of the dynamic impingement process and provide insights on how to control surface wettability to achieve a desired droplet spreading and rebounding process.

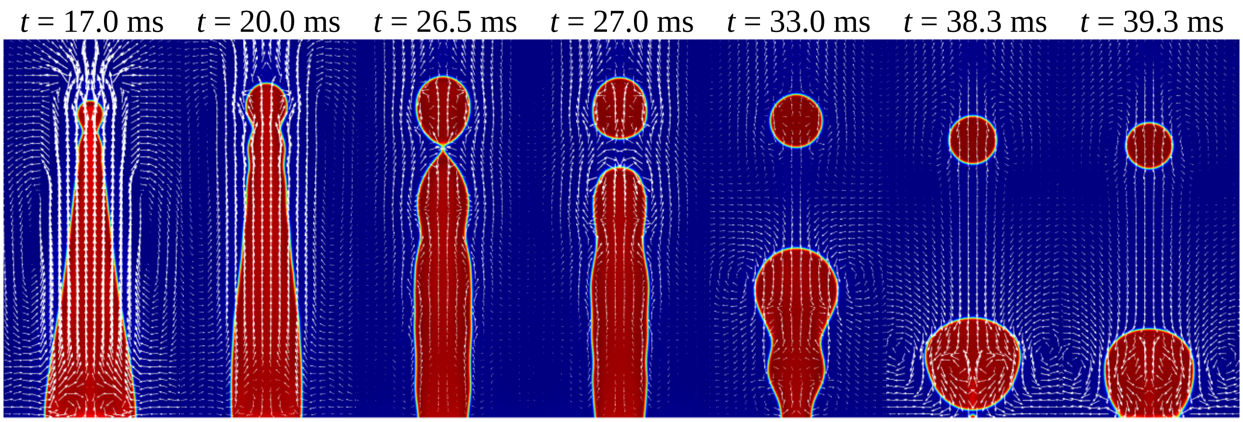


**Figure 7.** Time sequence of water droplet recoiling process obtained with a constant contact angle of 95$^o$.

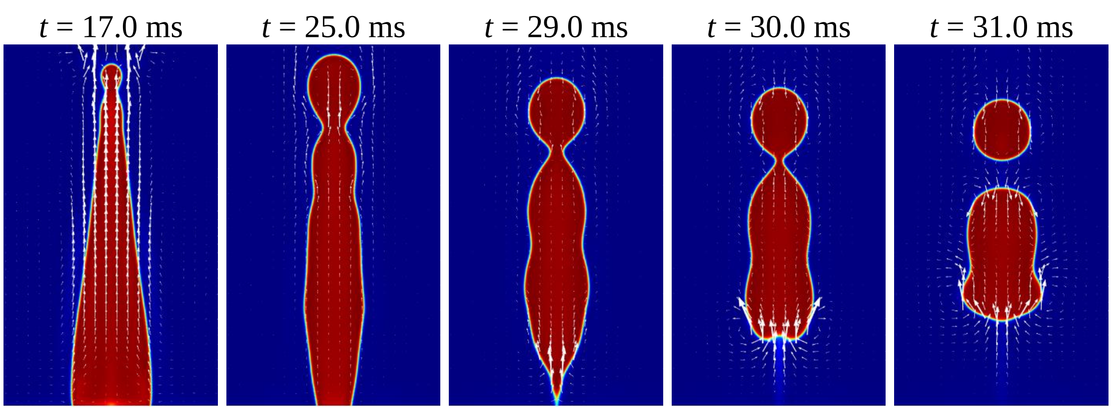


**Figure 8.** Time sequence of water droplet recoiling process obtained with a constant contact angle of 100$^o$.

## References

1. Amit Gupta and Ranganathan Kumar, Droplet impingement and breakup on a dry surface, *Computers and Fluids*, **39**, 1696-1703 (2010).
2. V. Bertola, Dynamic wetting of dilute polymer solutions: the case of impacting droplets, Advances in Colloid and Interface Science, **193-194**, 1-11, 2013.
3. V. Bertola, An impact regime map for water drops impacting on heated surfaces, International J. of Heat and Mass Transfer, **85**, 430-437, 2015.
4. S. Sikalo and E.N. Ganic, Phenomena of droplet-surface interactions, *Experimental Thermal and Fluid Science*, **31**, 97-110 (2006).
5. S. Sikalo, M. Marengo, C. Tropea, and E.N. Ganic, Analysis of impact of droplets on horizontal surfaces, *Experimental Thermal and Fluid Science*, **25**, 503-510 (2002).
6. M. Rein, Phenomena of liquid drop impact on solid and liquid surfaces, Fluid Dyn. Res., **12,** 61–93,1993.
7. A.L. Yarin Drop impact dynamics: splashing, spreading, receding, bouncing. Annu Rev Fluid Mech., **38**, 159–92, 2006.
8. M. Marengo, C. Antonini, I.V. Roisman, C. Tropea, Drop collisions with simple and complex surfaces, Curr Opin Colloid Interface Sci, **16**, 292–302, 2011.
9. V.V. Khatavkar, P.D. Anderson, P.C. Duineveld, H.E.H. Meijer, Diffuse-interface modelling of droplet impact, J. Fluid Mech. **58** (2007) 97-127.
10. I. Malgarinos, N. Nikolopoulos, M. Marengo, C. Antonini, M. Gavaises, VOF simulations of the contact angle dynamics during the drop spreading: standard models and a new wetting force model, Advances in Colloid and Interface Science, **212** (2014) 1-20.
11. N. Nikolopoulos, G. Bergeles, The effect of gas and liquid properties and droplet size ratio on the central collision between two unequal-size droplets in the reflexive regime, Int. J. of Heat and Mass Transfer, **54** (2011) 678-691.
12. J.Hu, R. Jia, K. Wan, X. Xiong, Simulation of droplet impingement on solid surface by the level set method, Proceedings of the COMSOL Conference 2014 Boston, Boston, MA, Oct. 8-10, 2014.
13. S. Tanguy, A. Berlemont, Application of a level set method for simulation of droplet collisions, Int. J. of Multiphase Flow, **31** (2005) 1015-1035.
14. Y. Guo, L. Wei, G. Liang, S. Shen, Simulation of droplet impact on liquid film with CLSVOF, Int. Communications in Heat and Mass Transfer, **53** (2014) 26-33.
15. K. Yokoi, D. Vadillo, J. Hinch, I. Hutchings, Numerical studies of the influence of the dynamic contact angle on a droplet impacting on a dry surface, Physics of Fluids, **21** 072102 (2009).
16. B.H. Bang, S.S. Yoon, H.Y. Kim, S.D. Heister, H. Park, S.C. James, Assessment of gas and liquid velocities induced by an impacting liquid drop, Int. J. of Multiphase Flow, **37**(2011) 55-66.
17. Y. Tanaka, Y. Waashio, M. Yoshino, and T. Hirata, Numerical simulation of dynamic behavior of droplet on solid surface by the two-phase lattice Boltzmann method, *Computers and Fluids*, **40** (2011) 68-78.
18. M. Cheng, J. Lou, A numerical study of splash of oblique drop impact on wet walls, Computer and Fluids, **115** (2015) 11-24.
19. W. Zhou, D. Loney, A. G. Fedorov, F. L Degertekin, D. W. Rosen, Impact of polyurethane droplets on a rigid surface for ink-jet printing manufacturing, $21^{st}$ Solid Freeform Fabrication Symposium, 2010, Austin, TX.
20. W. Zhou, D. Loney, A. G. Fedorov, F. L Degertekin, D. W. Rosen, Shape evolution of droplet impingement dynamics in ink-jet manufacturing, *$22^{nd}$ Solid Freeform Fabrication Symposium*, Aug.8-10, 2011, Austin, TX.
21. S. Dong, On imposing dynamic contact-angle boundary conditions for wall-bounded liquid-gas flows, Comput. Mehtods Appl. Mech. Engrg., **247-248** (2012) 179-200.
22. P.D.M. Spelt, A level-set approach for simulations of flows with multiple moving contact lines with hysteresis, J. of Computational Physics, **207** (2005) 389-404.
23. Y. Sui, P.D.M. Spelt, An efficient computational model for macroscale simulations of moving contact lines, J. of Computational Physics, **242** (2013) 37-52.
24. A.A. Saha, S.K. Mitra, Effect of dynamic contact angle in a volume of fluid (VOF) model for a microfluidic capillary flow, J. of Colloid and Interface Sci., **339** (2009) 461-480.
25. COMSOL4.3b CFDModuleUserGuide.pdf
26. S. Shiaffino and A.A. Sonin, Molten droplet deposition and solidification at low Weber numbers, *Phys. Fluids*, **9**, 3172-3187 (1997).


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# An Approach for Project Management Software Selection using Analytical Hierarchy Process

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## Abstract

This paper seeks to explore how considerations of analytical hierarchy process (AHP) can aid management and administration of multinational organizations in solving multiple attribute decision-making problems. The focus of the paper is project management software selection involving a large number of variables and constraints. Informed decision-making is vital for the success of enterprises. The Analytic Hierarchy Process (AHP) first proposed by Thomas L. Saaty in 1977 (Saaty, 1980) can be utilized effectively as a decision making tool and has been applied to a wide range of areas including Information Technology, Health Care Management, Supply Chain Management, Public administration, etc. With the use of AHP it is possible to give a problem that is qualitative in nature a pseudo-quantitative structure. This structure then can be used to arrive at decisions by expressing preferences for one attribute over another, and testing whether the preferences are consistent. This paper utilizes AHP for project management software selection, since studies focusing in this area are limited in the literature. With this motivation the paper structures the available data turning them into meaningful information to be used for project management software selection problem. The collected data consists of a number of variables, objectives, quantitative, and conflicting in nature. The study predominantly focuses of the literature review of AHP and proposes an approach to the use of AHP for selecting project management software.

## Keywords

Analytical Hierarchy Process (AHP), analytical hierarchy risk, decision making, project management, project management software.

## Introduction

Managing projects is a very challenging task and even more challenging is completing projects within budget and on time as well as meeting the industry's quality standards. Project management (PM) is clearly a risky endeavor with too many projects being cancelled before completion while too many others exceed their budgets, are completed beyond their target dates, or lack the expected quality. Therefore there is strong need for a project management software that aid to overcome all the above-mentioned challenges. This paper would state the use of the Analytical Hierarchy Process (AHP) in order to determine the appropriate project management software for any organization according to a set of criteria obtained as a result of the comprehensive literature review.

## Literature Review

In this paper, Analytical Hierarchy Process (AHP) has been used as a project management selection tool. AHP acts as a support system in solving problems in real world and is proven useful when the decision criteria are associated with considerable subjectivity.

Thomas L. Saaty first proposed AHP as a structured method for solving problems involving decision variables or decision attributes where at least some of these variables are qualitative in nature and cannot be measured (Saaty, 1980). After its introduction, the method has been applied to a wide range of problems. Despite the fact that the success of a project depends on several critical factors, the strength of AHP is its ability to analyze these critical factors using fairly elementary mathematics. This way, the method is able to structure complex problems that involve multiple decision makers and decision variables. AHP also has the ability to impose a quasi-quantitative character on decision problems, specifically to the variables that are not necessarily quantitative in nature. The method became very popular among companies due to its ability to transform non quantitative data to quasi quantitative data and has served as a major tool for decision making and adding value to any organization's growth and prosperity (Saaty, 1982; Arbel& Orgler,1990; Uzoka, 2005). AHP has been used in flexible manufacturing systems (Canada & Sullivan, 1989) and the selection of optimum resources in a chemical plant. It has also been applied to business crisis management, preventive maintenance, hiring processes, investor suitably analyses, public sector fund allocation problems, either alone or combined with meta-heuristics, SWOT analysis, and the data envelopment analysis (DEA).

## AHP Methodology

AHP is based on a set of pairwise comparisons to assess the strength of preferences among three or more alternatives available for a given problem. In related project management literature, the technique is widely applied as a tool for combining quantitative and qualitative approaches. The steps of the AHP approach can be summarized as below:

1. Define the decision goal along with alternative options and criteria for selection.
2. Define priorities among the characteristics of the attributes through judgments based on pairwise comparisons for each attribute.
3. Organize and standardize the collected hierarchical judgements so that the criteria will be prioritized according to their subjective importance.
4. Once the hierarchy is set create a matrix and compare the attributes with respective characteristics and the preference of one over another.
5. Determine a final decision based on the goal.

## Data Collection for Project Management Using AHP

Projects are known to be temporary in nature and comprise an objective with a definite beginning and an end (Salas-Morera, Arauzo-Azofra, García-Hernández, Palomo-Romero, & Hervás-Martínez, 2013). Therefore, the term Project Management can be defined as the process of directing the achievement of project objectives (Munns & Bjeirmi, 2005). More attributes and objectives increase the complexity of project management and hence necessitate the use of the project management software as a management tool. Organizations worldwide constantly strive for competitive advantage, and every year an advanced version of these PM tools with better and more advanced features than its previous version appears on the market, helping manage projects in an efficient way. However, it becomes very difficult to identify the organization's needs and the best software that would serve the purpose. This problem becomes more complex when a decision has to be taken with regards to continuing with the existing software or installing a new one.

In traditional project management, managers concentrate on monitoring project progress against schedules and budgets. However, more contemporary approaches embrace a variety of variables of control at different levels of the different phases of the project process, e.g., user contributions, project team task completion competency, and individual project team's performance (Bernroider & Ivanov , 2011). The value of the software highly depends on its ability to handle time, budget and schedules.

Managing different phases of the project life cycle is a challenging task and becomes even more difficult when the project team is divided across time zones in different corners of the world. Research conducted by Lie et al. emphasize the use of web-based project management software application, because of its ease of installation and accessibility (Liu, Chen, & Klein, 2010). Additional benefits such as platform independence; cost effectiveness, customizable and bigger range of device compatibility are also detailed in the study. These factors make the web-based project management software a prime contender for managing global projects.

Fortune and White (Fortune & White, 2006) discussed how successful project outcomes depend on several critical success factors, including the involvement of a suitable and qualified project team, and a competent project manager with good leadership skills. According to the study, a PM software is most effective when the application server and client are collocated.

Furthermore, during the literature survey indicates that it is important to avoid making decisions regarding software under extraordinary circumstances such as during an organizational change or unstable market conditions (Laslo & Goldberg, A.I. , 2001).

A review centric methodology has been used to finalize the software selection criteria that will be used in the proposed AHP methodology to measure each available attribute to the reach the final goal (Table 1).

Table 1. Software Selection Criteria for AHP Implementation

| Software Selection Criteria | Authors |
|---|---|
| Web Based Application | (Marques, Gourc, Lauras, & Lauras, 2011) (Bernroider & Ivanov , 2011) (Qu & Cheung, 2012) (Pinto, Dawood, & Pinto, 2011) (Turner, Ledwith, & Kelly, 2012) (Mahaney & Lederer, 2010) (Whitty & Maylor, 2009) |
| Client/Server Availability | (Guynes & Windsor, 2011) (Maire & Collerette, 2011) (Denyer, Kutsch, Lee-Kelley, & Hall, 2011) (Wierschem & Johnston, 2005) (Li, Lu, Kwak, & Dong, 2015) (Ruuska & Brady, 2011) |
| Time/Cost Calculation | (Marc Lappe a, 2014) (Kapsali, 2011) (Pemsel & Wiewiora, 2013) (Tam, Shen, & Kong, 2011) (Garel, 2011) (Hwang & Ng, 2013) (Doloi, 2011) (Marques, Gourc, Lauras, & Lauras, 2011) |
| Full Critical Path Coverage | (Yang & Kao, 2012) (Ahlemann, El Arbi, Kaiser, & Heck, 2013) (Söderlund & Maylor, 2012) (Garel, 2011) (Hwang & Ng, 2013) (Salas-Morera, Arauzo-Azofra, García-Hernández, Palomo-Romero, & Hervás-Martínez, 2013) (Artto, Kulvik, Poskela, & Turkulainen, 2011) |
| Resource management | (Lappe & Spang, 2012) (Holzmann, 2013) (Söderlund & Maylor, 2012) (Hwang & Ng, 2013) (Sommer, Dukovska-Popovska, & Steger-Jensen) (Doloi, 2011) (Salas-Morera, Arauzo-Azofra, García-Hernández, Palomo-Romero, & Hervás-Martínez, 2013) (Marques, Gourc, Lauras, & Lauras, 2011) (Palacios-Marqués, Cortés-Grao, & Lobato Carral, 2013) (Yaghootkar & Gil, 2012) (Denyer, Kutsch, Lee-Kelley, & Hall, 2011) |
| Document Management | (Holzmann, 2013) (Pemsel & Wiewiora, 2013) (Hwang & Ng, 2013) (Haffner, 2010) (Higgins, 2010) (Baban & Mokhtar, 2010) (Wood, 2012) (Fortune & White, 2006) (Teece, Pisano , & Shuen , 2002) (Kapsali, 2011) |
| Multiple and concurrent User Accessibility | (Doloi, 2011) (Muller & Turner, 2007) (Ruuska & Brady, 2011) (Hu, Li, & Teh, 2011) (Jung & Liu, 2012) (Qu & Cheung, 2012) (Ramteke & Talmale) |
| Invoicing/Procurement | (Solution, 2014) (Boggs, 2014) (O'Mahoney, Heusinkveld, & Wright, 2013) (Ripin, Jamieson, Meyers, Warty, Dain, & Khamsi, 2011) (Sundar, 2012) |
| Disaster Recovery/Backup | (Alecu, 2011) (Ahlemann, El Arbi, Kaiser, & Heck, 2013) (Ramteke & Talmale) (Grosskopf, Shepherd, & Oppenheim, 2006) (Denyer, Kutsch, Lee-Kelley, & Hall, 2011) |

Time is also a crucial factor and its effective management is highly influential on the success of projects. Time management involves important steps such as defining activities, sequencing activities, allocating and estimating resources for defined activities, duration and effort estimations, and development and control of the schedule.

In addition to time, cost calculation ability is also important in project management software. This feature involves a series of activities for estimating, allocating and controlling cost within the project. It involves determining a project and approving the required budget . It is also responsible for process planning that defines critical and non-critical tasks with the goal of preventing time frame and bottleneck problems.

Furthermore, an efficient resource management is also needed for efficient and effective deployment of organization resources. The organizational resource is carefully used when needed; such resources may include financial, inventory human skills, production resources and IT (information technology). The process of utilizing the company resource in a most effective and efficient way is prioritized, resource management can include ideas such as making sure one has enough physical resources for one's project, but not an overabundance as the product may not get used and may get wasted.

## Setup Preference

The evaluation criteria used for determining appropriate project management software were classified into nine main categories by using review centric methodology; so that Web Based Application, Client/Server Availability, Time/Cost Calculation, Full Critical Path Coverage, Resource management, Document Management, Multiple and concurrent User Accessibility, Invoicing/Procurement, Disaster Recovery/Backup are selected as the influential criteria (Table 2). Once the evaluation criteria have been finalized, the criteria set is embedded into a preference matrix. The AHP algorithm than performs a pair comparison where the strength/preference of each attribute would be compared against each criterion by assigning a preference/importance value according to the provided rating scale.

Table 2: Preference codes for pair comparison

| Preference # | Preference of A over B | Definition |
|---|---|---|
| 1 | None | Equal |
| 2 | Weak | Between equal and slightly More |
| 3 | Slightly More | Slightly better, slightly More Important |
| 4 | Moderate Plus | Between slightly more and more |
| 5 | Strong | Better more important |
| 6 | Strong Plus | Between more and much more |
| 7 | Very Strong | Much more |
| 8 | Very Strong Plus | Between much more and definitely much more |
| 9 | Absolute | Definitely much more |

Table 2 provides a hierarchical comparison for each attribute used in software selection.

Following this, each criterion would be pair compared against each other.

## Application of AHP Methodology

The general practice for developing an AHP analysis is to develop a separate set of matrices for each evaluator, or to have participants brainstorm until they arrive at a group decision for the required matrices. In this paper, collected responses are aggregated and inputted in the AHP model. The applicability of the AHP model is demonstrated via four generic project management software. The results are provided in (Table 3).

Table 3: Software selection criteria and codes.

| Software Selection Criteria | Code |
|---|---|
| Web Based Application | 1 |
| Client/Server Availability | 2 |
| Time/Cost Calculation | 3 |
| Full Critical Path Coverage | 4 |
| Resource Management | 5 |
| Document Management | 6 |
| Multiple and Concurrent User Accessibility | 7 |
| Invoicing/Procurement | 8 |
| Disaster Recovery/Backup | 9 |

## Analysis of results as per applications of the methodology

Implementing AHP using the data provided above the final ratings for each attribute are obtained (Table 4).

Table 4: Criteria ranking derived by implementing AHP

| **Software No** | **Category** | **Priority** | **Rank** |
|---|---|---|---|
| 1 | Web Based Application | 20.00% | **1** |
| 2 | Client/Server Availability | 18.80% | **2** |
| 3 | Time/Cost Calculation | 17.90% | **3** |
| 4 | Full Critical Path Coverage | 10.40% | 6 |
| 5 | Resource Management | 12.10% | **5** |
| 6 | Document Management | 1.80% | 9 |
| 7 | Multiple and Concurrent User Access | 3.00% | 8 |
| 8 | Invoicing/Procurement | 3.20% | 7 |
| 9 | Disaster Recovery/Backup | 12.80% | **4** |

Once these attributes were ranked the AHP principle that works on the eigenvector comparison principles results in the following matrix provided in Table 5.

Table 5: AHP Normalized performance preference matrix

| Web Based Application | Client/Server Availability | Time/Cost Calculation | Critical Path | Resource Manage-ment | Document Manage-ment | Multiple User Access | Invoicing | Disaster Recovery |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 5 | 1 | 5 | 6 | 3 | 4 | 9 |
| 0.5 | 1 | 2 | 4 | 2 | 5 | 6 | 3 | 6 |
| 0.2 | 0.5 | 1 | 3 | 2 | 4 | 9 | 6 | 8 |
| 1 | 0.25 | 0.33 | 1 | 1 | 2 | 3 | 4 | 5 |
| 0.2 | 0.5 | 0.5 | 1 | 1 | 9 | 7 | 6 | 5 |
| 0.16 | 0.2 | 0.25 | 0.5 | 0.12 | 1 | 1 | 2 | 3 |
| 0.33 | 0.16 | 0.11 | 0.33 | 0.14 | 1 | 1 | 4 | 3 |
| 0.25 | 0.33 | 0.16 | 0.25 | 0.16 | 0.5 | 0.25 | 1 | 1 |
| 0.11 | 0.16 | 0.12 | 0.2 | 0.2 | 0.33 | 0.33 | 1 | 1 |
| 0.28 | 0.19 | 0.16 | 0.09 | 0.13 | 0.03 | 0.04 | 0.02 | 0.02 |

In order to provide a better understanding; the basics of pairwise comparison in matrix form for n numbers of vectors are provided prior to the comparison. Mathematically, a square matrix with positive entries is called a specific PCM denoted by A, if it is transitive. Also any transitive matrix can be expressed as the product of a column vector u and a row vector v T as:

$$A = uv^T \qquad \text{(Eq. 1)}$$

Therefore in this case the value of u and v is 9 so the number of comparison would be 36. Below are the weights that are based on the principal eigenvector of the decision matrix.

Principal Eigen value = 9.963
Eigenvector solution: 7 iterations, delta = 9.6E-9

Number of comparisons = 36 Consistency Ratio CR = 8.3%

Table 6. Eigenvector Comparison for the 9 criteria

| Codes | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 2 | 3 | 2 | 9 | 3 | 4 | 1 |
| 2 | 0.5 | 1 | 2 | 4 | 2 | 9 | 6 | 3 | 1 |
| 3 | 0.5 | 0.5 | 1 | 3 | 2 | 9 | 8 | 6 | 2 |
| 4 | 0.3 | 0.3 | 0 | 1 | 1 | 9 | 3 | 4 | 2 |
| 5 | 0.5 | 0.5 | 1 | 1 | 1 | 9 | 7 | 6 | 1 |
| 6 | 0.1 | 0.1 | 0 | 0.1 | 0.1 | 1 | 1 | 1 | 0.1 |
| 7 | 0.3 | 0.2 | 0 | 0.3 | 0.1 | 1 | 1 | 2 | 0.1 |
| 8 | 0.3 | 0.3 | 0 | 0.3 | 0.2 | 1 | 0.5 | 1 | 0.5 |
| 9 | 1 | 1 | 1 | 0.5 | 1 | 9 | 9 | 2 | 1 |

Table 6 explains the results depicted in Table 4 supporting the ranking achieved by each criterion. Therefore, web based application has emerged as the priority 1 criterion for the organization in selecting project management software.

## Conclusions

In this paper, the evaluation criteria used for determining the appropriate project management software were classified into nine main categories. However, the decision process can always express a preference that is more desirable in order to achieve the preset objectives. Based on the test results obtained and the rank of each criterion, it is concluded that the web based application has emerged as the highest priority criteria for the organization when selecting project management software. This is compatible with the results of the comprehensive literature review provided in the study.

In conclusion, this paper demonstrates the applicability of AHP as a multifunctional, flexible and an efficient approach for project management software selection.

## References:


1. Ahlemann, F., El Arbi, F., Kaiser, M. G., & Heck, A. (2013). A process framework for theoretically grounded prescriptive research in the project management field. *International Journal of Project Management* , 43-56.
2. Alecu, F. (2011). How to make a software project ready for external backup – rules to be followed. Oeconomics of Knowledge.
3. Artto, K., Kulvik, I., Poskela, J., & Turkulainen, V. (2011). The integrative role of the project management office in the front end of innovation. *International Journal of Project Management* , 408-421.

4. Baban, H., & Mokhtar, S. (2010). Online Document Management System for Academic Institutes. *Information Management, Innovation Management and Industrial Engineering* , 315-319.
5. Bernroider, E. W., & Ivanov , M. (2011). IT project management control and the Control Objectives for IT and related Technology (CobiT) framework . *International Journal of Project Management* , 325-336.
6. Boggs, M. (2014). Innovative approaches to procurement.(Management & Careers). *Government Finance Review,* , 46.
7. Denyer, D., Kutsch, E., Lee-Kelley, E. (., & Hall, M. (2011). Exploring reliability in information systems programmes. *International Journal of Project Management* , 442-454.
8. Doloi, H. K. (2011). Understanding stakeholders' perspective of cost estimation in project management. *International Journal of Project Management,* , 622-636.
9. Fortune, J., & White, D. (2006). Framing of project critical success factors by a systems model . *International Journal of Project Management* , 53-56.
10. Garel, G. (2011). A history of project management models: From pre-models to the standard models. *International Journal of Project Management* , 110-121.
11. Grosskopf, K. R., Shepherd, W. J., & Oppenheim, P. E. (2006). Assessing the financial feasibility of utility-provided backup power during project site planning.(Author abstract).
12. Guynes, C., & Windsor, J. (2011, January). Revisiting Client/Server Computing. *Journal of Business & Economics Research* , 17-22.
13. Haffner, S. (2010). DOCUMENT MANAGEMENT GO GREEN, SAVE GREEN. *GPSolo* .
14. Higgins, J. (2010). Development Efforts Help Move the Ball Down the Field.(Document Management Systems). *The CPA Technology Advisor* , 6-13.
15. Holzmann, V. (2013). A meta-analysis of brokering knowledge in project management. *International Journal of Project Managemen* , 396-407.
16. Hu, Y., Li, K. H., & Teh, K. C. (2011). Performance analysis of two-user cooperative multiple access systems with DF relaying and superposition modulation. *IEEE Transactions on Vehicular Technology* , 3118-3126.
17. Hwang, B.-G., & Ng, W. J. (2013). Project management knowledge and skills for green construction: Overcoming challenges. *International Journal of Project Management* , 272-284.
18. Jha, K., & Iyyer, K. (2007). Commitment, coordination, competence and the iron triangle. . *International Journal of Project Management 25* , 527-540.
19. Jung, E., & Liu, X. (2012). Opportunistic spectrum access in multiple-primary-user environments under the packet collision constraint. *IEEE/ACM Transactions on Networking* , 501-514.
20. Kapsali, M. (2011). Systems thinking in innovation project management: A match that works. *nternational Journal of Project Management* , 31-42.
21. Lappe, M., & Spang, K. (2012). Investments in project management are profitable: A case study-based analysis of the relationship between the costs and benefits of project management. *nternational Journal of Project Management* .
22. Laslo, Z., & Goldberg, A.I. . (2001). Matrix structures and performance: the search for optimal adjustment to organizational objectives. . *EEE Transactions on Engineering Management EM-48 (2)* , 144-156.
23. Li, Y., Lu, Y., Kwak, Y. H., & Dong, S. (2015). Developing a city-level multi-project management information system for Chinese urbanization. *International Journal of Project Management* , 510-527.
24. Lindkvist, L. (2008). Project organization: exploring its adaptation properties. . *International Journal of Project Management* , 13-26.
25. Liu, J.-C., Chen, H.-G., & Klein, G. (2010). Task completion competency and project management performance: the influence of control and user contribution . *International Journal of Project Management* , 220-227.
26. Mahaney, R. C., & Lederer, A. L. (2010). The role of monitoring and shirking in information systems project management. *International Journal of Project Management* , 14-25.
27. Maire, S., & Collerette, P. (2011). International post-merger integration: Lessons from an integration project in the private banking sector. *International Journal of Project Management* , 279-294.
28. Marc Lappe a, K. S. (2014, May). nvestments in project management are profitable: A case study-based analysis of the relationship between the costs and benefits of project management. *International Journal of Project Management* .
29. Marques, G., Gourc, D., Lauras, M., & Lauras, M. (2011, December). Multi-criteria performance analysis for decision making in project management. *International Journal of Project Management* , 1057-1069.

30. Muller, R., & Turner, J. (2007). Matching the project manager's leadership style to project type . *International Journal of Project Management 25* , 21-32.
31. Munns, A. K., & Bjeirmi, B. F. (2005). The role of project management in achieving project success. *International Journal of Project management* , 81-86.
32. O'Mahoney, J., Heusinkveld, S., & Wright, C. (2013). Commodifying the Commodifiers: The Impact of Procurement on Management Knowledge. *Journal of Management Studies* , 204-235.
33. Palacios-Marqués, D., Cortés-Grao, R., & Lobato Carral, C. (2013). Outstanding knowledge competences and web 2.0 practices for developing successful e-learning project management. *International Journal of Project Management* , 14-21.
34. Pemsel, S., & Wiewiora, A. (2013). Project management office a knowledge broker in project-based organisations. *nternational Journal of Project Managemen* , 396-427.
35. Pinto, J. K., Dawood, S., & Pinto, M. B. (2011). Project management and burnout: Implications of the Demand–Control–Support model on project-based work. *International Journal of Project Management* .
36. Qu, Y., & Cheung, S. O. (2012). Experimental evaluation of logrolling as an effective mediating tactic in construction project management. *International Journal of Project Management* , 113-127.
37. Ramteke, A., & Talmale, G. Access Control Mechanism for Multi-user Data Sharing in Social Networks. *2014 Fourth International Conference on Communication Systems and Network Technologies*, (pp. 578 - 582). Bhopal.
38. Ripin, D. J., Jamieson, D., Meyers, A., Warty, U., Dain, M., & Khamsi, C. (2011). Antiretroviral procurement and supply chain management. *Asian Cardiovascular and Thoracic Annals* , 268-278.
39. Ruuska, I., & Brady, T. (2011). Implementing the replication strategy in uncertain and complex investment projects. *International Journal of Project Management* , 422-421.
40. Söderlund, J., & Maylor, H. (2012). Project management scholarship: Relevance, impact and five integrative challenges for business and management schools. *International Journal of Project Management* , 686-696.
41. Saaty, T. L. (1980). *The Analytical Hierarchy Process.* New York: McGraw-Hill.
42. Salas-Morera, L., Arauzo-Azofra, A., García-Hernández, L., Palomo-Romero, J. M., & Hervás-Martínez, C. (2013). PpcProject: An educational tool for software project management. *Computers and Education* , 181-189.
43. Solution, T. C. (2014). *Computers, Software; Cortex Expands Partnership with Pandell to Deliver a Fully Automated Invoice Management Solution.* Atlanta: NewsRx.
44. Sommer, A. F., Dukovska-Popovska, I., & Steger-Jensen, K. (n.d.). Barriers towards integrated product development — Challenges from a holistic project management perspective. *International Journal of Project Management [Peer Reviewed Journal]* .
45. Sundar, S. (2012). EFFICIENT PROCUREMENT MANAGEMENT IN UK CONSTRUCTION PROJECTS. *International Journal of Marketing and Technology* , 142-166.
46. Tam, V. W., Shen, J., & Kong, J. K. (2011, January). Impacts of multi-layer chain subcontracting on project management performance. *International Journal of Project Management* , 108-116.
47. Teece, D., Pisano , G., & Shuen , A. (2002). Dynamic capabilities and strategic management. . *Strategic Management Journal* , 509-533.
48. Turner, R., Ledwith, A., & Kelly, J. (2012). Project management in small to medium-sized enterprises; Tailoring the practices to the size of company. *Management Decision* , 942-957.
49. Whitty, S. J., & Maylor, H. (2009). And then came Complex Project Management (revised). *International Journal of Project Management* , 304-312.
50. Wierschem, D., & Johnston, C. (2005). The role of project management in university computing resource departments. *International Journal of Project Management* , 640-659.
51. Wood, L. C. (2012). Better Discovery Through Document Management. *Information Management, Innovation Management and Industrial Engineering* .
52. Yaghootkar, K., & Gil, N. (2012). The effects of schedule-driven project management in multi-project environments. *International Journal of Project Management* , 127-140.
53. Yang, J.-B., & Kao, C.-K. (2012, April). Critical path effect based delay analysis method for construction projects. *International Journal of Project Management* , 385-397.


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# An Efficient Video Steganography Algorithm Based on BCH Codes

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## Abstract

In this paper, in order to improve the security and efficiency of the steganography algorithm, we propose an efficient video steganography algorithm based on the binary BCH codes. First the pixels' positions of the video frames' components are randomly permuted by using a private key. Moreover, the bits' positions of the secret message are also permuted using the same private key. Then, the secret message is encoded by applying BCH codes (*n*, *k*, *t*), and XORed with random numbers before the embedding process in order to protect the message from being read. The selected embedding area in each Y, U, and V frame components is randomly chosen, and will differ from frame to frame. The embedding process is achieved by hiding each of the encoded blocks into the 3-2-2 least significant bit (LSB) of the selected YUV pixels. Experimental results have demonstrated that the proposed algorithm have a high embedding efficiency, high embedding payload, and resistant against hackers.

## Keywords

Video Steganography, BCH Codes, Linear Block Code, Embedding Efficiency, Embedding Payload.

## Introduction

Due to technological advances and the speed of the Internet, people are concerned that their personal information will be stolen by hackers. In today's society, many data hiding algorithms and steganographic algorithms have been introduced in order to protect valuable information. Steganography is one of the methods that protects and hides valuable data from unauthorized people without hackers having any suspicion of the data's existence. The Human Visual System (HVS) cannot recognize a slight change that occurs in the cover data such as audio, image and video[1,2]. Unfortunately, many strong steganography analyzing tools have been provided to unauthorized users in order for them to retrieve valuable secret data previously embedded in cover objects. The weakness of some steganography algorithms occur through steganalytical detectors because of the lack of security and embedding efficiency in these algorithms.

The embedding efficiency and the embedding payload are two important factors that every successful steganography system should take into consideration[3]. First, the steganography scheme that has a high embedding efficiency translates to a good visual quality of stego data and a less amount of host (carrier) data are going to be changed[4]. Any obvious distortion to the viewers will increase the probability of the attacker's suspicion, and the secret information can be easily detected by some of the steganalysis tools[5]. These kinds of schemes are difficult to detect by the steganalytical detectors. The security of the steganography scheme depends directly on the embedding efficiency[6]. Second, a high embedding payload means that the capacity of secret information to be hidden inside host data is large. These two factors, embedding efficiency and embedding payload, contradict one another. Once, the data embedding efficiency is increased, the data embedding payload is decreased. These two factors will change depending on the users' requirements and the type of steganography scheme[4,7]. The remainder of the paper is organized as follows: Section 2 presents some related work. Section 3 introduces an overview of the Linear Block Code and BCH codes, and then presents the proposed steganography algorithm. Section 4 presents experimental results and discussion. Section 5 provides the conclusion.

## Related Work

Feng et al. proposed a novel of a video steganography scheme based on motion vectors as carrier data in order to embed the secret message in H.264 video compression processing. The algorithm also uses the principle of linear block codes to reduce motion vectors' modification rate. The algorithm has a good visual quality of stego data, which is proved by the low modification rate of motion vectors. The Peak Signal to Noise Ratio that was obtained in both *Flower* and *Foreman* videos are more than 37 dB[8]. Hao et al. proposed a novel video steganography method based on a motion vector by using matrix encoding. A motion vector component that has high amplitude among both horizontal and vertical components is chosen to embed the secret message. The HVS can identify the change that occurs when the object is moving slowly. However, if the same object moves quickly, the HVS will not be able to recognize the change that occurs. Motion vectors with large sizes are selected for embedding the secret messages. The macro blocks that are moving quickly will generate motion vectors with large amplitudes. The direction of macro blocks depends on the motion vectors' components. For example, if the vertical component is equal to zero, then the macro block direction is moving vertically. The visual quality of the tested videos that were obtained is more than 36 dB[9]. Rongyue et al. proposed an efficient BCH coding for steganography which is embedding the secret information inside a block of cover data by changing some coefficients. Authors have improved the computational time of the system and the complexity becomes low because of the system's linearity[10]. Liu et al. proposed a robust data hiding scheme in an H.264 compressed video stream, where they have prevented a drift of intra-frame distortion. To give the system more robustness, the authors have encoded the message using BCH codes before the embedding process. The host data is the DCT coefficients of the luminance Intra frame component. The obtained results have a high visual quality and robustness against hackers[11].

## The Proposed Steganography Algorithm

The proposed algorithm uses an uncompressed video stream which is based on the frames as still images. The video sequences are divided into frames, and each frame's color space is converted to *YCbCr*. The reason for using *YCbCr* color space is to remove the correlation between Red, Green, and Blue colors. The luminance (*Y*) component represents the brightness data, which the human eye is more sensitive to than the other color components. As a result, the chrominance (*CbCr*) components can be subsampled in the video stream and some information might be discarded.

*A. Linear block codes*

Any specific block code is defined as a linear block code if the sum of any two codewords equals a new codeword. Furthermore, a binary linear block code includes a linear block code that contains a block of binary bits. A binary linear block code (*n*, *k*) consists of $2^{\mathrm{k}}$ columns and $2^{\mathrm{n-k}}$ rows in a linear code array. This code is an *n*-dimensional vector space and a *k*-dimensional subspace $V_n = \{(C_0, C_1, C_2, \dots, C_{n-1}) | C_j \epsilon\, GF(2)\}$. *N* refers to the length of the codeword and *K* refers to the number of symbols in each codeword. In the standard array, it is not possible for two equal vectors to exist in the same row. For example, if *C* is a (*n*, *k*) code on the Galois Field GF (2), then:

- Each coset has $2^{\mathrm{k}}$ vectors.
- All *F* vectors of length *n* belong to coset of *C*.
- If *C*+*Z* is a coset of *C* and *F* as belonging to (*C*+*Z*), then *C*+*Z*=*C*+*F*.

*B. BCH codes (7, 4, 1)*

Bose, Chaudhuri, and Hocquenghem invented the BCH encoder. It is one of the most powerful random cyclic code methods, which can be used for detecting and correcting errors in a block of data. The BCH codes are different from the Hamming codes because BCH can correct more than one bit. A binary BCH (*n*, *k*, *t*) can correct errors of a maximum *t* bits for codewords of the length *n* $(\mathrm{c}_0, \mathrm{c}_1, \mathrm{c}_2, \dots, \mathrm{c}_{\mathrm{n}-1})$ and message length *k* $(\mathrm{a}_0, \mathrm{a}_1, \mathrm{a}_2, \dots, \mathrm{a}_{\mathrm{k}-1})$. Encoded codewords and messages can both be interpreted as polynomials, where $\mathrm{a(x)} = \mathrm{a}_0 + \mathrm{a}_1\mathrm{x}^1 + \cdots + \mathrm{a}_{\mathrm{k}-1}\mathrm{x}^{\mathrm{k}-1}$, and $\mathrm{c(x)} = \mathrm{c}_0 + \mathrm{c}_1\mathrm{x}^1 + \cdots + \mathrm{c}_{\mathrm{n}-1}\mathrm{x}^{\mathrm{n}-1}$. When *m* and *t* are any positive integers where $(\mathrm{m} \geq 3)$and $(\mathrm{t} < 2^{\mathrm{m}-1})$, there will be a binary BCH codes with the following properties:

- Block codeword length $n = 2^m - 1$
- Message length $k$
- Maximum correctable error bits $t$
- Minimum distance $d_{min} \geq 2t + 1$
- Parity check bits $n - k \leq mt$

The BCH codes inventors decided that the generator polynomial g(x) will be the polynomial of the lowest degree in the Galois field GF (2), with $\propto, \propto^2, \propto^3, \dots, \propto^{2\mathrm{t}}$ as roots on the condition that $\propto$ is a primitive of $\mathrm{GF}(2^{\mathrm{m}})$. When $\mathrm{M_i(x)}$ is a minimal polynomial of $\propto^{\mathrm{i}}$ where $(1 \leq \mathrm{i} \leq 2\mathrm{t})$, then the least common multiple (*LCM*) of 2*t* minimal polynomials will be the generator polynomial g(x). In this paper, the BCH codes (7, 4, 1) is used. The parity-check matrix *H* of the BCH codes[12,13] is described as follows:

$$H = \begin{bmatrix} 1 & \propto & \propto^2 & \propto^3 & \dots & \propto^{n-1} \\ 1 & (\propto^3) & (\propto^3)^2 & (\propto^3)^3 & \dots & (\propto^3)^{n-1} \\ 1 & (\propto^5) & (\propto^5)^2 & (\propto^5)^3 & \dots & (\propto^5)^{n-1} \\ . & . & . & . & \dots & . \\ . & . & . & . & \dots & . \\ . & . & . & . & \dots & . \\ 1 & (\propto^{2t-1}) & (\propto^{2t-1})^2 & (\propto^{2t-1})^3 & \dots & (\propto^{2t-1})^{n-1} \end{bmatrix} \quad (1)$$

*C. Data embedding stage*

Data embedding is the process of hiding a secret message inside cover videos. This process converts the video stream into frames. Each frame separates into the Y, U and V components of color space. For security purposes, the pixels' positions of Y, U, and V components are permuted by using a special key ($Key_1$). Also, characters of the secret message are converted into an array of binary bits. In order to change the bits' positions of the secret message, the entire bits' positions within the array are permuted using $Key_1$. After permutation, the array is divided into 4-bit blocks. Then, each block is encoded by the BCH (7, 4, 1) encoder. The outcome of the 7-bit encoded block (consists of 4-bit message and 3-bit parity) is XORed with the 7-bit number. These numbers are randomly generated by using $Key_2$. In order to select the locations for hiding the secret message into the frame components, $Key_2$ is utilized. In other words, $Key_2$ chooses random rows and columns for data embedding in each disordered Y, U, and V component. The embedding process is achieved by hiding each of encoded blocks into the 3-2-2 LSB of the selected YUV pixels. The pixels of the YUV components will be repositioned in order to the original frame pixel positions to produce the stego frames. Finally, the stego video is constructed from these stego frames. The block diagrams of the data embedding stage and the data extracting stage are illustrated in Fig. 1 and Fig. 2, respectively.

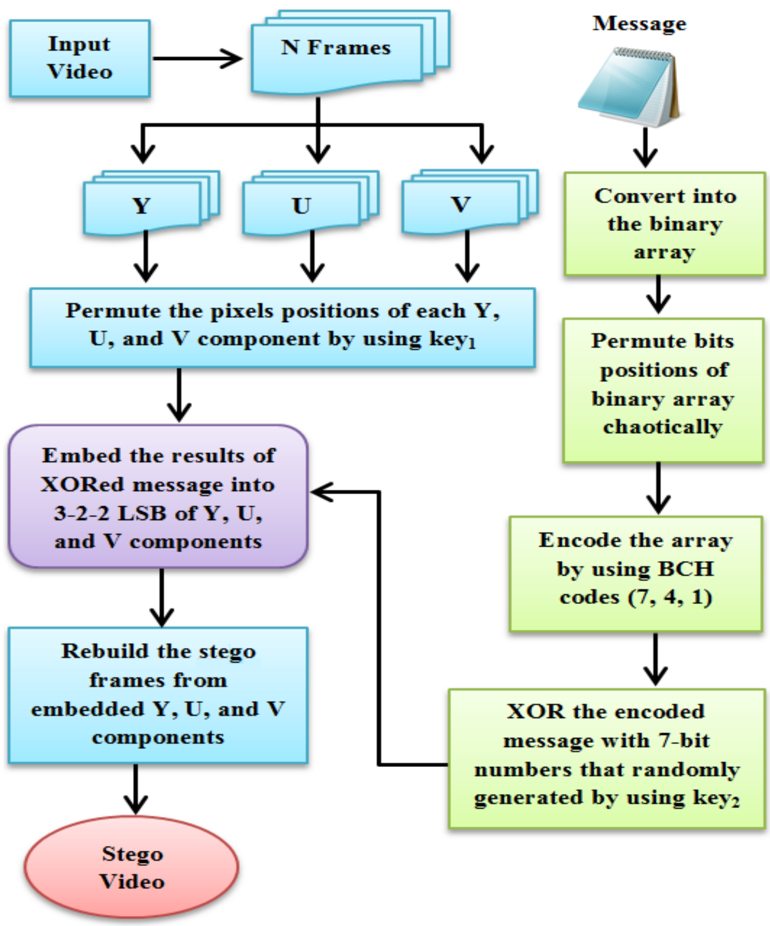


Fig. 1: Block diagram for data embedding stage.

*D. Data extracting stage*

Data extracting is the process of retrieving the secret message from the stego videos. This process is achieved by converting the distorted videos into frames. Then, each frame is partitioned into Y, U and V components. In every Y, U, and V component, the pixels' positions are permuted by using $Key_1$. The process of extracting the secret message from YUV components is accomplished by taking out 3-2-2 LSB in each selected pixel. The obtained message block will be XORed with the 7-bit number that is generated by using $Key_2$. The outcomes of 7 bits are decoded by the BCH (7, 4, 1) decoder in order to produce 4-bit blocks. These blocks are stored into a binary array. Since the message of entire bits is permutated prior to the data embedding process, the permutation process of the entire binary array to the original bits order will be performed again. Then, the binary array of bits will be converted into the characters of the secret message. The purpose of using two keys and the XOR operation is to improve the security and robustness of the proposed algorithm. These keys are only shared between sender and receiver, and used in both the data embedding and extracting processes.

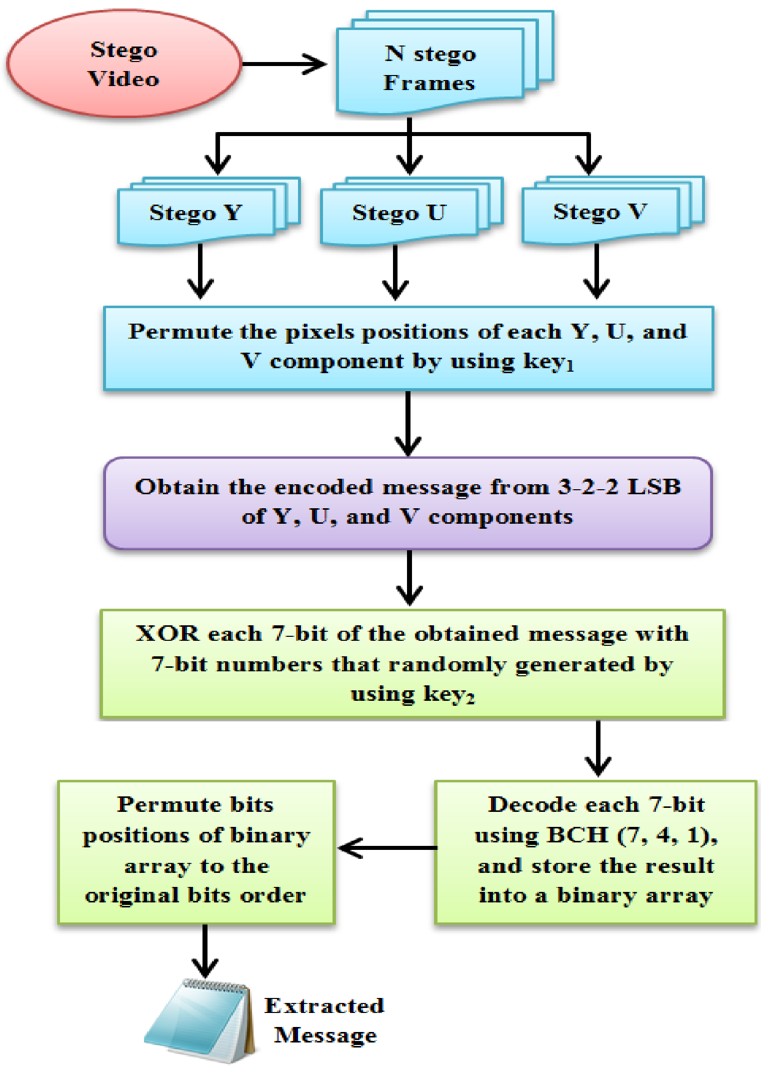


Fig. 2: Block diagram for data extracting stage.

## Experimental Results and Discussion

A database of eight standard of Common Interchange Format (CIF) video sequences is used, with the video resolutions equaled to (288 x 352), and the format represented by 4:2:0 YUV. Video sequences are equal in length to 300 frames. A text file consisting of alphabet characters is used as a secret message. This work is implemented using MATLAB program to test the proposed algorithm's performance. The Peak Signal to Noise Ratio (*PSNR*) is a visual quality measurement which is used to compute the difference between the original and the stego video frames. *PSNR* is calculated by the following equation:

$$PSNR = 10 * Log_{10}\left(\frac{{MAX_O}^2}{MSE}\right) \qquad (2)$$

And Mean Square Error (MSE) is calculated as follows:

$$MSE = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}[O(i,j) - S(i,j)]^2}{m * n} \qquad (3)$$

Where *O* and *S* denote the original and stego YUV frame components, respectively, and *m* and *n* are the video resolutions.

Fig. 3 illustrates the *PSNR*s of 300 stego frames for the *Hall* video. In Fig. 4, the *PSNR*s of 300 *Stefan* stego video frames are shown. Fig. 5 illustrates the *PSNR*s of 300 stego frames for the *Foreman* video. By using our proposed algorithm, the obtained visual quality is similar to the original videos' visual quality. In general, *PSNR*s are greater than 55 dB, and the V component has a better visual quality among the three components. The reason of V component has a better visual quality among other components is because V component has a longest wavelength.

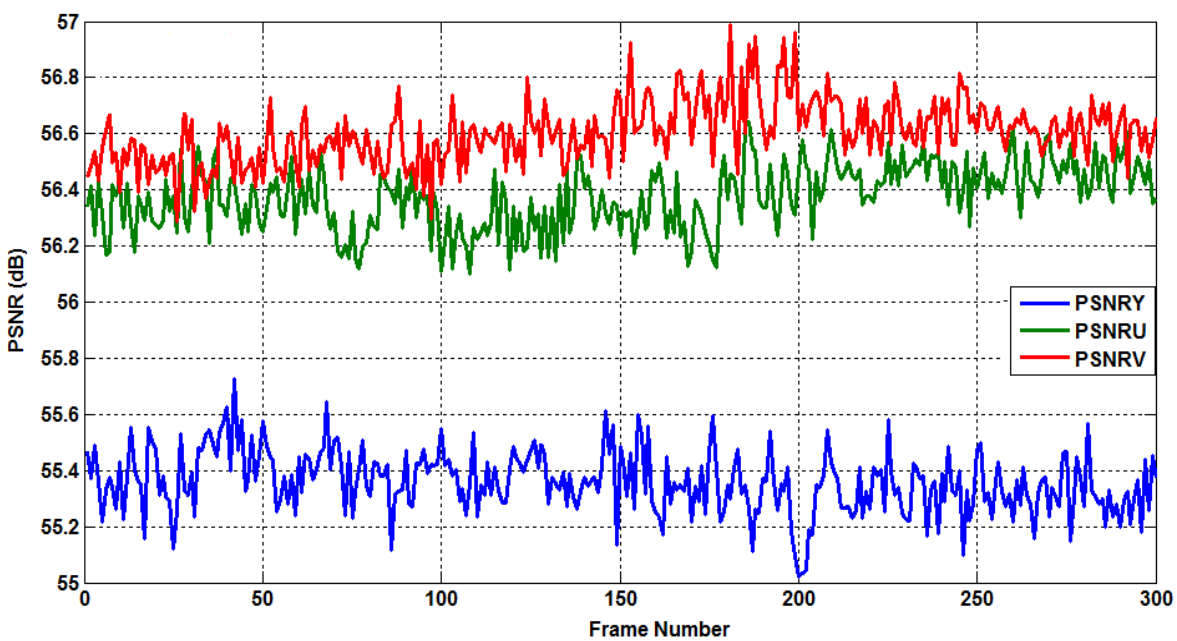


Fig. 3: *PSNR* of 300 stego frames for the *Hall* video.

In Table 1, the *PSNR* for eight video sequences is shown for each Y, U, and V component, separately. The visual quality of the stego videos is the same as the original videos' visual quality because all *PSNR* values are greater than 55 dB.

**TABLE 1 THE AVERAGES OF *PSNRY*, *PSNRU*, AND *PSNRV* FOR ALL VIDEOS**

| Sequences | Frame No. | *PSNRY* | *PSNRU* | *PSNRV* |
|---|---|---|---|---|
| ***Hall*** | *1-100* | **55.401** | **56.34** | **56.52** |
| | *101-200* | **55.357** | **56.324** | **56.649** |
| | *201-300* | **55.317** | **56.459** | **56.638** |
| ***Stefan*** | *1-100* | **55.381** | **56.388** | **57.031** |
| | *101-200* | **55.359** | **56.378** | **57.058** |
| | *201-300* | **55.359** | **56.343** | **57.028** |
| ***Coastguard*** | *1-100* | **55.335** | **56.064** | **56.454** |
| | *101-200* | **55.324** | **56.082** | **56.406** |
| | *201-300* | **55.323** | **56.055** | **56.395** |
| ***Mobile*** | *1-100* | **55.321** | **56.546** | **56.667** |
| | *101-200* | **55.306** | **56.517** | **56.608** |
| | *201-300* | **55.285** | **56.456** | **56.57** |
| ***Foreman*** | *1-100* | **55.287** | **56.484** | **56.621** |
| | *101-200* | **55.297** | **56.479** | **56.616** |
| | *201-300* | **55.285** | **56.463** | **56.605** |
| ***Container*** | *1-100* | **55.362** | **56.527** | **56.665** |
| | *101-200* | **55.329** | **56.476** | **56.674** |
| | *201-300* | **55.334** | **56.464** | **56.672** |
| ***News*** | *1-100* | **55.527** | **56.567** | **56.381** |
| | *101-200* | **55.512** | **56.539** | **56.369** |
| | *201-300* | **55.498** | **56.535** | **56.364** |
| ***Akiyo*** | *1-100* | **55.385** | **56.482** | **56.561** |
| | *101-200* | **55.31** | **56.511** | **56.564** |
| | *201-300* | **55.348** | **56.481** | **56.504** |

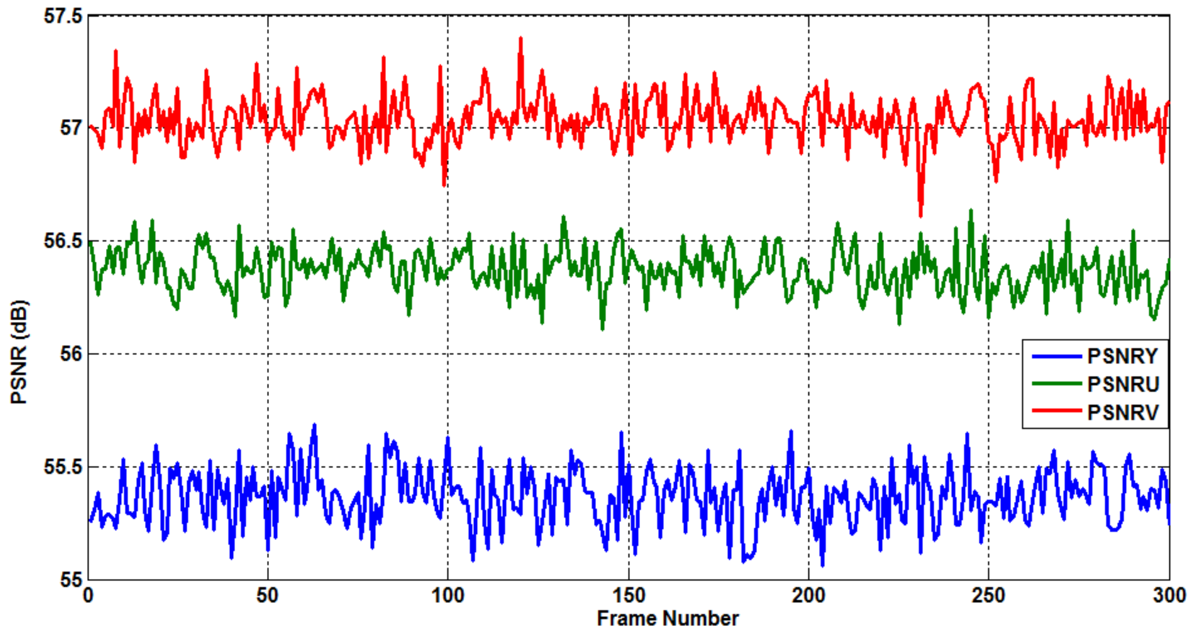


Fig. 4: *PSNR* of 300 stego frames for the *Stefan* video.

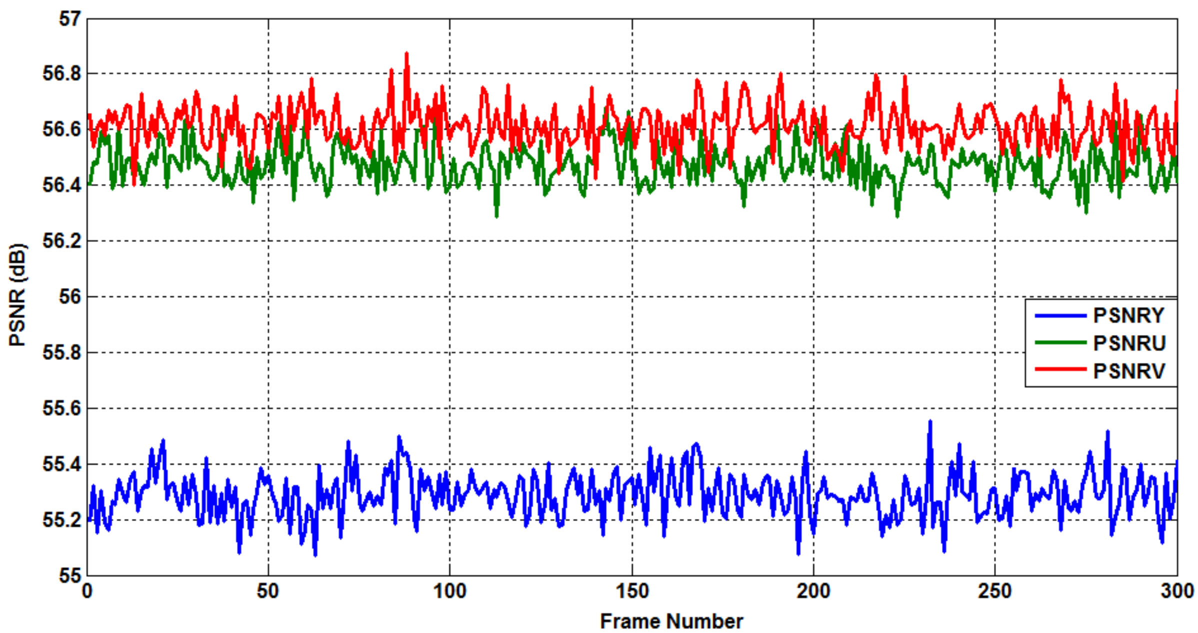


Fig. 5: *PSNR* of 300 stego frames for the *Foreman* video.

Fig. 6 shows the comparison of the visual quality between eight stego videos. The *PSNR* of each component, Y, U, and V is separately calculated, in which the average equals 300 frames per video. The values of *PSNR*s are between 55 and 57 dBs, which are considered excellent visual quality results.

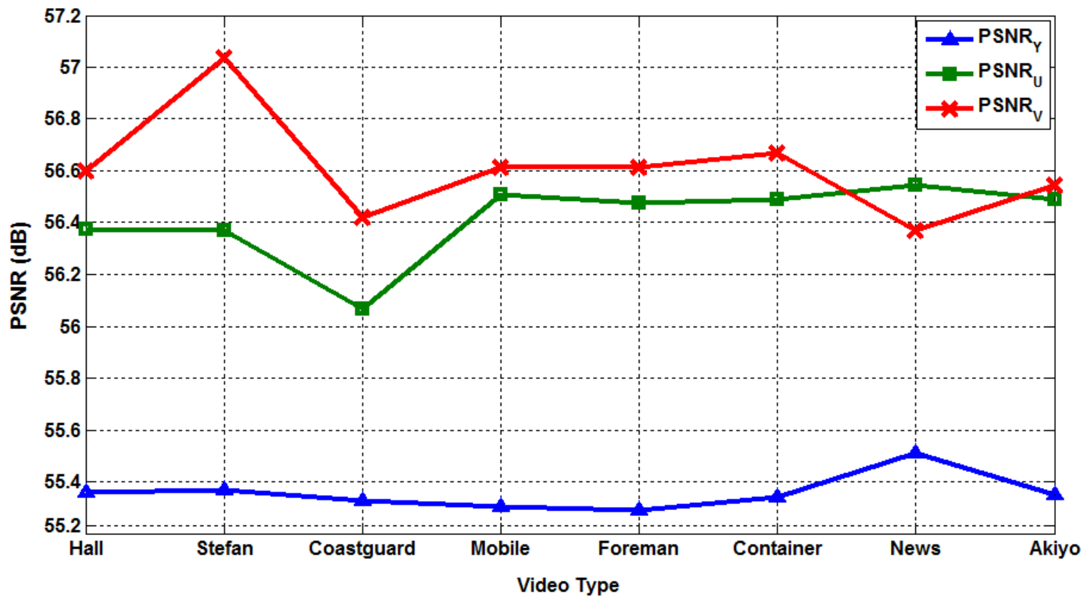


Fig. 6: Comparison between the averages of the *PSNRY*, *PSNRU*, and *PSNRV* components for eight video sequences

## Conclusion

In this paper, an efficient video steganography based on the BCH codes concepts has been proposed. The proposed steganography algorithm utilized frames as still images. It divides the video stream into frames, and then converts the frames to the YUV format. This algorithm is considered a high embedding efficiency algorithm due to the low modification on the cover data that translates into perfect visual quality in the stego videos. The visual quality is measured by the *PSNR* metric, and all the obtained experimental results have a *PSNR* above 55 dB. By achieving a good visual quality for stego videos, hackers will have difficulty retrieving secret messages. The security of our proposed algorithm has been satisfied by having more than one key to embed and extract the secret message. In addition to the secret keys that we have used, we also encoded and decoded the message with the BCH codes (7, 4, 1).

Experimental results prove both a high embedding efficiency and a high embedding payload of the proposed algorithm exist. The visual qualities of the stego videos are the same as the original video visual qualities. The *PSNR* of stego videos is above 55 dB. In each video frame, the embedding capacity is 246 Kbits, and can increase up to 405 Kbits without any noticeable degradation in the visual quality.

## References

1. Yuh-Ming, H. and J. Pei-Wun. *Two improved data hiding schemes*. in *Image and Signal Processing (CISP), 2011 4th International Congress on*. 2011.
2. Mstafa, R.J. and C. Bach. *Information Hiding in Images Using Steganography Techniques*. in *American Society for Engineering Education (ASEE Zone 1), 2013 Zone 1 Conference*. 2013.
3. Mstafa, R.J. and K.M. Elleithy. *A highly secure video steganography using Hamming code (7, 4)*. in *Systems, Applications and Technology Conference (LISAT), 2014 IEEE Long Island*. 2014.

4. Chin-Chen, C., T.D. Kieu, and C. Yung-Chen. *A High Payload Steganographic Scheme Based on (7, 4) Hamming Code for Digital Images*. in *Electronic Commerce and Security, 2008 International Symposium on*. 2008.
5. Guangjie, L., et al. *An Adaptive Matrix Embedding for Image Steganography*. in *Multimedia Information Networking and Security (MINES), 2011 Third International Conference on*. 2011.
6. Jyun-Jie, W., et al. *An embedding strategy for large payload using convolutional embedding codes*. in *ITS Telecommunications (ITST), 2012 12th International Conference on*. 2012.
7. Mstafa, R.J. and K.M. Elleithy. *A Novel Video Steganography Algorithm in the Wavelet Domain Based on the KLT Tracking Algorithm and BCH Codes*. in *Systems, Applications and Technology Conference (LISAT), 2015 IEEE Long Island*. 2015.
8. Feng, P., et al. *Video steganography using motion vector and linear block codes*. in *Software Engineering and Service Sciences (ICSESS), 2010 IEEE International Conference on*. 2010.
9. Hao, B., L.-Y. Zhao, and W.-D. Zhong. *A novel steganography algorithm based on motion vector and matrix encoding*. in *Communication Software and Networks (ICCSN), 2011 IEEE 3rd International Conference on*. 2011.
10. Rongyue, Z., et al., *An Efficient Embedder for BCH Coding for Steganography.* Information Theory, IEEE Transactions on, 2012. **58**(12): p. 7272-7279.
11. Liu, Y., et al., *A Robust Data Hiding Algorithm for H. 264/AVC Video Streams.* Journal of Systems and Software, 2013.
12. Hoyoung, Y., et al., *Area-Efficient Multimode Encoding Architecture for Long BCH Codes.* Circuits and Systems II: Express Briefs, IEEE Transactions on, 2013. **60**(12): p. 872-876.
13. Mstafa, R.J. and K.M. Elleithy. *A High Payload Video Steganography Algorithm in DWT Domain Based on BCH Codes (15, 11)*. in *Wireless Telecommunications Symposium (WTS), 2015*. 2015.


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# A Quantitative Forensic Investigation of Causal Factors which Impact Residential Structures during a Major Hurricane

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## Abstract

The forensic investigation of damaged residential structures following a hurricane allows students to examine the forces of a hurricane on a residential structure. This research investigates the actual damage. This is not a predictive model, but a statistical model that examines the causal factors of the damage. This provides the students with numerous possibilities for interdisciplinary research in design, construction and improvement of building codes. The general principal upon which this new model is based provides potential for further development and has the capacity to analyze data drawn from different geographical areas. The general principles and characteristics of the model in terms of how it has been developed form the basis of the remainder of this paper. A regression model is applies to examine the damage factors.

**Key Words:** Hurricane, Damage, Statistical Model, Residential

## Introduction

Current hurricane models used to predict the levels of damage incurred from a major hurricane are all predictive in nature. Currently available models are insufficient to actually analysis the damage levels and the interrelated causal agents to identify the conditions that caused failure of the structure. This research provides a basis for evaluation of the forensic investigation of the causal factors which impact residential structures. The derived results are applied to prevent similar damage in future impacts.

When conducting research projects proper and applicable research methods are required to insure accurate and reasonable procedures to complete the project. This project provides an avenue for students to perform pure research by collecting data following a hurricane and if possible, prior to the storm by examining the structures in a high probability zone. To conduct investigative research, as in the evaluation of the damage caused to a structure in a hurricane, the chosen method must draw upon applied techniques[1].

The use of physical models or computer animated models, although they employ historical data, do not evaluate the true conditions that the structures are subjected to, nor do they take into account the construction types, or conditions that are not visible. The unforeseen conditions are those caused by previous hurricanes weakening the structure, the corrosive effects of the salt air, or those caused by the homeowner by not maintaining the structure properly. By combining historical data and actual damage data the individual structure is represented in the model. The historical and actual hurricane data is publicly available through several governmental agencies and research universities. This provides the basis for a comprehensive analysis of the community.

***Problem Statement***

Current hurricane models are mostly predictive in nature; they are designed to provide data for typical damage that could be inflicted given the size and intensity of the storm. For students to examine the damage to residential structures an evaluative statistical model is needed to analyze the various elements of a hurricane incident and the physical makeup of the affected community. The model provides students with the opportunity to collect data, perform statistical analysis, and develop an understanding of the opposing forces on residential structures and the ultimate damage. The final aspect is for students to understand the conditions that are inflected by a hurricane and how to best assist in preventing damage. This is accomplished by:

- Investigation of natural disasters
- Understanding the dynamics of a hurricane
- Use of Geographical Information System (GIS)
- Improvements of building techniques
- Research methodology
- Statistical analysis

## Methodology

Students are to select a hurricane prone area and investigate the damage caused in this zone. Students will have to perform research and examine the damage caused and quantify this information. Statistical analyses are performed on the collected data and write a professional report. This provides an in depth evaluation of the affected area and demonstrates the full impact of natural storm occurrences. The use of Geographical Information System (GIS), statistical analysis requires the students to coordinate the data to appropriate statistical process for properly analyzing the data to achieve information that is applicable to making residential structures less prone to damage from a hurricane.

## Test Example Research Area

The township of Kure Beach, NC was selected for its unique characteristics. The first attribute of the town of Kure Beach is the area receives a higher than average instance of hurricanes. This area protrudes out into the Atlantic Ocean, intersecting the Gulf Stream, which delivers warm waters along the coast. Another condition that makes the county unique is the elevation of Kure Beach. Kure Beach is the highest elevation on the east coastline at thirty-four feet above sea level[2]. The varying elevations of the community allows for studying the differing effects of surge, flooding and sweeping winds upon the structures.

Lastly, the corrosive effects of the ocean coupled with the higher air moisture content along coastal areas have led to numerous instances of moisture damage[2]. The Kure Beach area is designated as having the highest incidents of corrosion problem of all towns located along the United States eastern seaboard. The caustic effects of the ocean and varying construction practices are recognized causal agents contributing to the depletion of structural integrity of the local coastal structures[2].

Available data were sourced from the New Hanover County Department of Emergency Management, FEMA, and the New Hanover County GIS and Tax Departments. The relevant agencies were willing to cooperate with the research and its purposes. GIS database files covering a specific geographical area are presented on a map of the area. Different types of data are displayed upon the map in layers, or themes, with the result that each theme can be integrated separately depending upon how the database has been assembled. Some of the data required for the research was not held in existing files for the Kure Beach, NC area. Therefore, this data had to be acquired in written format. Data acquired in this way was entered manually into the previously acquired data files in a new layer.

The test model incorporates eighteen variables that each relates to the three main categories: the built environment, the natural environment and historical surge data. In a post hurricane investigation these are the available variables. The variables are presented in Table 1. The built environment is represented by variables $H_1$ through $H_7$. The factors collected from Project Impact (a GIS program supplied by FEMA) [3] are indictors of historically data; they are represented with variables $H_8$ through $H_{11}$. Variables $H_{12}$ through $H_{14}$ are the natural environment's contribution to the model. The surge levels collected from the NOAA are historical surge data and represented in the model in $H_{15}$ through $H_{16}$ [4]. The coastal buffers, $H_{17}$, were created to determine the effects of the proximity of the structure to the coastline. This factor does not take into consideration the topographical elevations. Variable $H_{18}$ was collected by NOAA following Hurricane Fran by measuring watermarks left behind on structures pilings and other permanent fixtures[5].

Table 1 Table of Variables

| Title | Description | Title | Description |
|---|---|---|---|
| $H_1$ | Year Built (YB) | $H_{10}$ | Flood risk (FR) |
| $H_2$ | Square footage (SF) | $H_{11}$ | Surge risk (SR) |
| $H_3$ | Perimeter length (PL) | $H_{12}$ | Soil (S) |
| $H_4$ | Lot size (LS) | $H_{13}$ | Topographical elevations (TE) |
| $H_5$ | Building value (BV) | $H_{14}$ | Wetlands (WL) |
| $H_6$ | Evaluation teams (ET) | $H_{15}$ | Slow surge (SS) |
| $H_7$ | Code date (CD) | $H_{16}$ | Fast surge (FS) |
| $H_8$ | Risk summary (RS) | $H_{17}$ | Coastal buffers (CB) |
| $H_9$ | Flood risk (FR) | $H_{18}$ | Watermark (WM) |

The analysis of the above variables has several interconnections. The differing variables are used to evaluate the dependent variable damage value. Pre evaluation of a hurricane prone area will provide additional variables specific to the structure (i.e. the amount of glazing, type of roof system, width of the roof overhang, current condition of the structure, etc.)

## Data Analysis

The derived data using GIS information (structure location, elevations, surge and flood zones, etc.), presented in the differing layers, is exported to an Excel spreadsheet. The derived data is specific to the individual structures. Damage evaluation teams categorize the damage into three categories: 2%, 25% and 100%, with 100% indicating that the structure is a total loss. The estimated damage value is determined following the hurricane by trained FEMA evaluation teams. The initial use of the construction damage is used to obtain federal relief dollars using a set average replacement cost figure. The cost of the damage inflicted to the structure is determined by multiplying the percent damage times the structures cost in U.S. dollars (per the structures cost at the time of the hurricane). Tax values are separated to coincide with the three categories to represent the level of damage cost. With the data entered in the spreadsheet provides a means to sort the information in any manner required. Only residential structures that are occupied by the Owner year round are investiaged. This eliminates rental properties, with making the assumption is made due to the fact that rental property is often rented by the week with numerous occupants and that the structure is not maintained or treated properly as one that is occupied consistently by the Owner.

Normally, a single factor alone does not significantly damage the structure, but collectively the factors cause failure in a structure, as a whole or in part. These interrelationships are analyzed statistically within the model. The proposed model calculates the percentage of damage in dollar amounts using the current tax value as a base figure. The regression model is implemented to evaluate the damage. The regression formula will take on a conceptual form of:

$$D = \beta o + \beta H + \beta nf + \beta BE + \varepsilon$$

Where:

$D$ = The damage value in US dollars
$\beta$ = Regression coefficient
$\beta o$ = Constant
$\beta H$ = Hurricane factors
$\beta nf$ = Natural factors
$\beta BE$ = Built environment factors
$\varepsilon$ = Residuals

The objective of the regression model is to test the damage variable against the selected variables to determine those factors that are statistically significant. The regression model may be used to test the hypothesis or to create a predictor model. In the instance that the model is used as a predictor, the Adj $R^2$ value must be at or above the ninetieth percentile (90%)[1]. The model is only testing the hypothesis to evaluate the causal factors of the hurricane. The differences between the available variables were tested at the .05 level of significance.

## Results

To perform the statistical analysis a series of computer generated regression models were constructed. Using the statistical analysis program, SPSS, the regression model evaluates the data that best fits the available data and produces the highest level of significance. In these scenarios the selected variables (the complete set of eighteen variables per 367 structures) are entered one at a time by the computer to select the best fit. In each of the models developed the variables are considered significant level of 0.05. The backwards model presents the highest degree of significance and utilizes the greatest number of variables to examine the damage to residential structures. The backwards pass model contains nine variables out of the original eighteen and all the variables are above the 0.05 level. Of the eighteen variables nine were eliminated for falling below the ten percent level of confidence. Of the remaining variables they achieved a 0.05 confidence level or better. The Beta, standard error, t score and the significance level for each of the significant variables are presented in Table 2.

Table 2 Backwards Model

| Variable | β | Std. Error | t | Calculated Significance |
|---|---|---|---|---|
| Constant | 1.990 | .208 | 9.553 | 99 |
| Perimeter length (PL) | .002 | .001 | 2.468 | 95 |
| SF of Bld. Footprint | -5.28E-05 | .000 | -20779 | 99 |
| Building value (BV) | 5.194E-06 | .000 | 9.196 | 99 |
| Damage Teams | -.064 | .013 | -4.760 | 99 |
| Code Date | .120 | .034 | 3.533 | 99 |
| Flood Risk | .058 | .026 | 2.239 | 95 |
| Erosion Risk | .208 | .030 | 6.907 | 99 |
| Surge Risk | .123 | .036 | 3.455 | 99 |
| Topo. Elevations | .040 | .013 | 3.153 | 95 |

## Individual Findings

The following analysis presents the nine elements identified in the regression model individually within this section. The collective results are presented in this section. The significance of the results is determined through the regression analysis. The nine variables selected for their significance are presented along with the implications for future damage mitigation. As a further comparison the statistically determined variables are also examined in terms of the three code date ranges.

## Code Date (CD)

The code date category was created using the major dates of the Southern Building Code and Hurricane Resistant Residential Construction Code evolution and the structures age. Structures were sorted by age as they pertain to the proper category of building code evolution. The intended purpose of this category is to determine the building code ability to create a structure that can resist a major hurricane. The separations of the three categories are:

| Division | Dates |
|---|---|
| 1 | 1900 to 1970 |
| 2 | 1971 to 1990 |
| 3 | 1991 to 1996[6] |

The important element derived from the results of the research is focused around the building code variable. The element of the enforcement of the codes is adequately addressed and not considered an element in the analysis of the data, except for erosion control. Other elements analyzed provide insight to the problematic elements of the building codes. Other elements are possible such as the decline of craftsmanship, poor materials or the lack of corrosion resistant restraints. The craftsmanship problems could be in the form of the construction process, as the construction process is operating at a rate that is too high with the use of modern equipment such as pneumatic nail guns, which leads to overshooting the nail or missing the framing member, thus reducing the holding strength of the framing and sheathing materials. Once the envelope of the structure is opened to the ravages of the hurricane strength winds the rest of the structure is in jeopardy.

**Erosion Risk (ER)**

The erosion variable was determined to have significant impact upon structures ability to withstand a major hurricane. Building codes require that pilings are imbedded to resist the erosion factor and that the foundations are raised to protect the substructure from erosion. In many locations along the coast line requires an engineer's stamp on the prints. Erosion causes undermining of the structures foundation. This condition thus leads to the collapse of a structure as the foundation is washed out removing the support. This condition purposes a high level risk to those structures located in the proximity of the ocean[7].

**Surge Risk (SR)**

A comparison of the frequency of structures residing within four hurricane strength zones indicates that the largest percentage are within the category four and five hurricane threat. The coastal areas received the highest level of surge damage as expected; however newer homes located at the coast received a higher level of damage in relation to the building code date. Comparison of the surge risk to the code dates could indicate that building codes do not adequately provide ample protection for structures to withstand the damage of a major hurricane. The inundation of surge waters is a power force that inflicts a high degree of damage to new and older structures alike[8].

**Flood Risk (FR)**

The flood risk frequency statistics indicate that the greater number of structures resides on the high ground, and damage levels are the greatest at the coast. The evaluation of the code date variable shows that the structures in the intermediate levels are the newest, with one of the higher damage levels residing in one of the areas supported by the newer building codes. When examining the damage levels, the structures on the high ground received greater damage. This analysis also shows that the older structures received less flood damage. The code dates vary from the erosion risk variable and shows independence between erosion and flooding[9].

## Topographical Elevations (TE)

The topographical elevations variable indicates a high frequency of new structures that receive a greater amount of damage. The frequency of the structures within the topographical levels is greater at the nine feet above sea level location. The mean damage levels are also higher at the coastline. Further evaluation shows that that the newer structures and those built using the most recent building codes are located at the coast. From examination of the data, the conclusion that the building codes are not effective in providing protection to structures is supported[3].

## Perimeter Length (PL)

It is shown that there is a relationship between the length and height of the walls around the buildings perimeter and damage. This is indicated because the surface area of walls has a direct relation to the wind damage levels. The expected results would indicate that the greater the wall length the larger the surface area for wind to react adversely against, intern causing a higher damage level[3].

## Lot Size (LS)

The lot size in conjunction with the perimeter length is a determinant of the density of housing in a particular road or street area. The density of the community is considered relational to the amount of possible debris, the increased probability of damage and imposed wind forces. The smaller the lot size the greater the structural density and increase of funneling of the air, thus increasing the wind pressure. The wall heights of the structure would also assist the creditability of the lot size variable[3].

## Building Value (BV)

The building value serves as a means to estimate the quality level of the structure. This is based on the assumption that the Owner's annual income corresponds with the value of the building and that in turn an appropriate proportion of that wealth will be invested in the maintenance of the building. It is postulated that increased maintenance will enhance a structures performance when subjected to a hurricane and therefore that damage can be expected to reduce in association with higher building valuations.

## Evaluation Teams (ET)

The evaluation team variable represents the geographical areas that the damage evaluation teams were assigned to document the extent of the structural damage. The evaluation team's duty is to evaluate the extent of damage within the predetermined areas. The areas that the teams investigate have nothing to do with the storm levels, but simply represent zones of possible growth, with seven two person teams evaluating the damage levels. The areas are random, but they are visually evenly divided through the community. The inclusion of the damage assessment teams' zones is to evaluate the different areas of the community. In accomplishing these tasks the teams evenly represented the areas in Kure Beach to provide a graph representing of the diversity of the population and displaying the density of the area[10].

## Conclusion

Students can derive useful information by analyzing damage caused by a hurricane. The experience of applying statistical analysis to determine damage factors the application of the data derived to the initial design; shape, location, structural attributes and to examine the natural surroundings is an important lesson for designers and constructors. It is the responsibility of all parties involved in the residential construction project to provide a safe and durable structure.

In the results of the test evaluation the overall conclusion drawn from the data analysis is that the newer structures did not perform as well as the older structures, statistically. This could indicate that the building codes are inadequate for the area. A large number of the damaged structures fall under the newest building codes. The codes are an important aspect to review, as they are the controlling factor for the assurance of quality construction. All of the structures are governed by the same codes all along the coastline. Making the assumption that it is the building codes that are at fault, as presented from the data, could indicate a false positive. Examining the time durations during these time periods developments and common use of nail guns come on line and the surge in construction places a strain on building inspectors to effectively examine structures in detail. The quality of construction is a more reasonable explanation for the effects on the residential structures.

The conclusion drawn is that the older, poorly built structures along the coast have been damaged and replaced from the impact of previous hurricanes. In addition, high ground areas are not inundated by coastal waters during a hurricane and do not have the chance to affect structure integrity. To examine the community damage levels, a damage ratio is applied to the community. This ratio divides the percentage of old structures (those built before 1970) and new structures (those built after 1970) by the percent of damage within the range, (Table 3). To examine the differences in the damage levels, the overall percent damage level is divided by the overall percent of the structures damaged. Damage levels are desired to be less than 1. The structures built prior to 1970 produced a ratio of 0.3125 and the structures built after 1970 produced a ratio of 1.6346. In addition to the damage ratio, it is noted that the percentage of old versus new structures is close to fifty percent each, but the damage sustained by the older structures is considerably reduced.

Table 3 Damage ratio

| | Old Structures | New Structures |
|---|---|---|
| Percentage of Population | 43 | 56 |
| Percentage of Damage | 15 | 85 |
| Damage Ratio | 0.3488 | 1.6038 |

By exposing the problem areas and subsequent changes to the building codes the improvements will increase the level of the building codes. Building codes are prescribed as minimal levels. In any instance, increasing of the minimal building standards will provide increased security to the local community. The research further contributes to the body of knowledge by providing a baseline to measure from in future evaluations and shows the need for increased amount and varied types of data. This data will become the future contributing factors for higher-level statistical evaluations and to determine if the changes are taking affect within the community. This helps students to have an applicable understanding and application of the building code.

## Future Research

The purposed model is applicable to students in numerous design disciplines. Examining other such natural disasters will indicate to the students the areas that were specifically affected by a hurricane. The knowledge derived from the research can be applied to designs and construction techniques in coastal regions. Interdisciplinary participation promotes cooperation to achieve the same goal and allows students with differing views of the same project work together to complete the project.

## References

1 Capen, M. (2002). "Testing Hypotheses, Parametric and Nonparametric". *Faculty Development Workshop, Summer 2002, Enhancing Basic Statistical Skills for Research Instruction*. ECU's Center for Faculty Development and the StatLab: Greenville, NC.
2 Hanna, B. (Personal Communication).
3 HAZUS. (1999). "Community Vulnerability Assessment Tool". NOAA Coastal Services Center: Charlestown, SC.
4 NOAA. (1996). "Fran High Water Mark". [Computer Software]. Charleston, SC: NOAA Coastal Service Center.
5 NOAA. (2003). "Community Vulnerability Assessment Tool". [Computer Software]. Charleston, SC: NOAA Coastal Service Center.
6 Mileti, D. S. (1999). "Disasters By Design". Joseph Henry Press: Washington D.C.
7 Hazard Identification. "Community Vulnerability Assessment Tool". NOAA Coastal Services Center. (2001). Retrieved from www.csc.noaa.gov/products/nchaz/htm/step1.htm
8 NC Storm Surge. "Explaining the Slosh Model". Hurricane Maps, Inc.: Leland, NC. (2012). Retrieved from http://www.ncstormsurge.com/slosh.html
9 "Multi-Hazards, HAZUS Natural Hazard Loss Estimation Methodology". *HAZUS News*. FEMA: Washington, D.C. (2002). Retrieved from http://www.fema.gov/hazus/ne_main.htm
10 Mayfield, M. (1996). "Preliminary Report, Hurricane Fran 23 August-8 September 1996". *National Hurricane Center*. (2003). Retrieved from www.nhc.noaa.gov/1996fran.html

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# Experimental Use of Recycled Materials to Construct a Solar Water Heater

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## Abstract

With increasing use of solar water heaters it is important that Construction Engineering Management students understand the basic operation of the system. Understanding the theory provided in a classroom and reinforcing these concepts in a lab demonstrates the function and efficiency of the systems. It is the purpose of this research for students to build and test various solar water heater alternatives using recyclable materials by examining various designs of solar water heaters for both cost effectiveness and functionality. Experimenting with various recyclable and inexpensive materials maintains a low cost and demonstrates to students that alternative systems are achievable at low cost. Recyclable materials such as aluminum cans as the absorber plate and PET bottles functioning as glazing reduce the cost and reuse disposable items. Two variations of test collectors were constructed to determine if the variations of efficiency, compared to the original design.

**Keywords**: Solar Water Heater; Recycled Material; Student Project; Cost Effective

## Introduction

The installation of residential solar water heaters is on the increase. In 2010 there were 35,464 solar water heating systems were in use in the United States[1]. Providing students with knowledge of solar water heaters is necessary of several disciplines. This project is connected with a mechanical and electrical course for Construction Engineering Management students. Purchasing test equipment is cost prohibitive for most programs. As an example; to deliver a sufficient amount of solar hot water using commercially constructed systems for four to five residents the cost varies from $8,000, to $10,000[2]. Utilizing several disciplines in the design and build process allows the students to work together and to have a greater understanding of complexities of solar hot water construction and installation. The added advantage of using recyclable materials presents the use of alternative materials and the cost savings.

To reduce the installation costs of domestic solar water heater (DSWH) inventive people are tuning to constructing their own systems using many different materials and methods. In conducting an internet search of available designs, there are 830,000 posted. There are designs that emulate production systems. These designs utilize innovative solutions at a fraction of the cost, enticing the constructing of systems. The cost effectiveness of constructing a DSWH system recues the initial installation cost and the reduction of energy consumption making the structure

## System Variation

In examining available online plans, several plans utilize differing materials. This research is based on the premise of using low cost materials and incorporating repurposed recyclable materials. Jose Alano and his family have constructed a system using Polyethylene Terephthalate (PET) bottles (soft drink bottles) and used black painted tetra pack cartons (milk cartons). The basic system has a CPVC pipe inside a PET bottle (which functions as the glazing) with the tetra pack carton cut in a manner in which the carton makes contact with the pipe as a collector plate (Figures 1 and 2)[3]. Both the pipe and the tetra pack cartons are painted matte black to increase the absorbency of solar radiation, thus heating the water.

Mr. Alano's system is located in Brazil in the city of Tubarao-SC. The city is located at 28.3 degrees latitude in the southern hemisphere. The currently installed system is four bottles in length, approximately 92 cm (36 1/4 inches). The current application is installed as a thermosiphon system on his roof. The thermosiphon configuration saves in the installation, operational and maintenance costs[3]. Definitive data of the system installed in Brazil is not available.

The system designed and built by Mr. Alano and his family has used materials that normally would have ended in a landfill and were redirected to generate hot water for their home. In Mr. Alano's design the tetra pack cartons contain a limited amount of aluminum (5%) and the other 95% is polyethylene and cellulose material[3] to absorb heat for transferring the heat in the pipes. Current literature indicates that Mr. Alano's system heats the water to 52 degrees Celsius[3].

Figure 1: Current Installed System[3]

Figure 2: Close up of PET bottles and tetra packaging collection plate[3]

## Materials and Solar Irradiation

In an article by Patterson and Miers[4] a series of experiments were conducted using differing commonly available water pipes (copper, PVC, CPVC, PEX, PE and steel) to determine if there is any difference in the functionality of the six common water pipes. The six tubing types listed are the common materials recommended for use for owner constructed solar water heaters[5]. The results of the previously mentioned research indicate that there is no difference between the six different piping materials thermal conductivity in a DSWH. The six mentioned pipe materials were tested in a static solar water heater with an average temperature of 122.84 degrees Celsius and at an average time of the day of 15:30 hours in western North Carolina during the summer[4]. PVC pipe functions in the same manner as copper, is less expensive and is easier to work with.

The efficiency of the solar water heater is dependent on the transfer and absorption of heat. By increasing the heat absorbency and transfer rate the efficiency of the collector is too increased, thus there is a higher amount of heat available for heating the water. An open or circulating system, the heat transfer is expected to vary from that of a static system.

The measurement of energy received from the sun upon a surface are is known as solar irradiation. The standard measurement is kilowatts per square meter per day (($KWh/m^2$)/Day). The amount of solar radiation is based on the location of the measurement throughout the world. The readings are presented by the National Renewable Energy Laboratory (NREL)[6]. The information is collected and presented in both specific readings for various cities or maps that are available per month and annual maps. The amount of radiation that a specific area receives is primarily based upon the latitude and angle of the sun (which varies with the time of year). An area of the world that is near to the equator will receive a greater amount of radiation than that of areas that are closer to the poles. As the sunlight passes through the earth's layers of atmosphere and clouds a certain amount of radiation is diverted. In addition the there is a percentage of energy that is absorbed by earth with a percentage being reflected back into the sky[7]. The maps that are used are assembled and published by NREL[6]. Assumptions of the annual irradiation collected are not considered in this research. The annual ($KWh/m^2$)/Day for the test area in Vermont is interpreted as 3.5 to 4 and the comparative test system in *Tubarao-SC, Brazil is 4.5 to 5* ($KWh/m^2$)/Day[6].

## Problem Statement

Solar water heater systems for the use in the classroom are an expense that most programs cannot afford. A simplified schematic view of a production domestic solar water heaters (DSWH) typically consist of a flat plate of metal (copper or steel) overlaid with copper tubing in varying configurations through which fluids flow (water or antifreeze liquid). The transfer of the heat from the plate to the tubing all of which is enclosed in an insulated box and covered with glazing allowing sunlight to enter and then to the fluid enters the structure where domestic water is heated directly or through a heat transfer system. This research expands upon the original design by Mr. Alano using recycled materials by testing four different configurations to attempt to increase the efficiency and collect definitive data. This study is designed for students to examine the differing test apparatus' examining differing reflective and heat absorbing materials in conjunction with using recycled materials. When the differing materials are used in a solar collector is there a variation between the configurations? The expected results will show that the temperatures are increased, while keeping the cost of the collector at an affordable price and ecologically friendly. The other expected result is an affordable system that shows that alternative materials can be applied and achieve comparable results. This is the first step before finalizing the design of the complete system.

## Methodology

This study examines four variations that students can conduct of Mr. Alano's basic system incorporating differing materials to improve the systems efficiency. The students are responsible for examining the variations of the collectors making modifications, collecting and assembling the systems and performing the tests. This requires that they work together in groups as they need to record the temperatures every hour, this means working around class schedules. The optimum solution is to install temperature sensors that are tied to a computer. This would provide information 24 hours a day, but at a higher cost. The theme of using recycled materials and simplicity are maintained throughout. The comparisons of the systems are conducted by examining the published data and the recorded data collected using the test apparatus. The original system was set the angle at that of his latitude and due north (as the system is located in the southern hemisphere). In setting the test system it is also set at the latitude of the test and due south (being in the northern hemisphere) with adjustments for true north. It is unknown if adjustments were made by Mr. Alano for the correction from true north verses magnetic north.

Before constructing an operational system, two test collectors were constructed to establish a baseline. Both house two Solar Tubes made of PET bottles and using CPVC pipe. The first Solar Tube is a simple device with only the CPVC pipe painted black threaded through the stack of PET bottles. The second Solar Tube is similar to the first with the addition of soda cans with both ends removed and painted matte black. All pipes are capped at the bottom with a standard cap glued in place with the top of the pipe having a male adapter to accept a threaded cap. The threaded cap allowed for checking the temperatures and to prevent evaporation. One can is inserted inside of each PET bottle, with a slight gap there is a continual column of painted cans. The collector frames were constructed using scrap plywood and 2x6 blocks top and bottom. The backing of one frame was painted white and the other frame bed was covered with unpainted aluminum for a reflective surface. Aluminum cans were cut and applied to the backing, verses purchasing roll aluminum. Each of the Solar Tubes was numbered. Solar Tube 1 has only a black pipe in the PET bottles with number Solar Tube 2 having soda cans installed. The backing of the frame bed was painted white. Solar Tube 3 is like number one and similarly Solar Tube 4 is configured as number two. The difference is the backing. Solar Tubes 3 and 4 are mounted on the frame with the aluminum coating. Figure 3 shows the two test apparatuses set in their test position, south facing with the angle of the collectors set at the latitude of the test site. Figure 4 shows a Solar Tube in its unpainted form for clarity. The differences between the original system and the experimental systems used in this article are the lengths (the original was four bottles long; the test system is 18 bottles long). The extra length of the Solar Tube allowed more surface area to heat the water. There is no backing on the original system and the tetra packaging is replaced with an aluminum can in one of the Solar Tubes on each of the two frames. The placing of the absorber system on different backing is to take advantage of the reflecting energy, creating a 360 collection system.

The test system cost was low as recycled materials were incorporated. The backing and end blocks were scrap material were salvaged from a local contractor's waste pile. The bottles and cans were gathered over a short period of time from the campus trash (in Vermont the cans and bottles are returnable so there is $7.20 in return fees). Purchasing the paint and piping materials cost is approximately $30.00 (depending on where the materials are purchased).

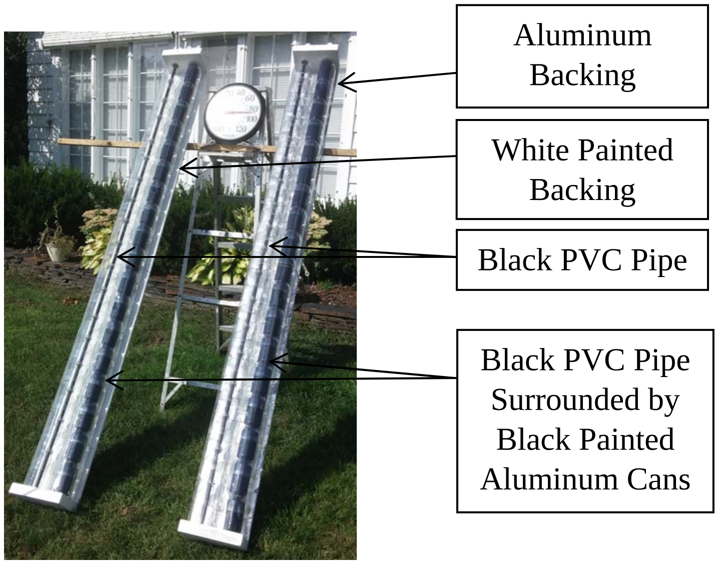


Figure 3: Experimental Frame and Set-up Figure 4: Close-up of Unpainted Solar Tube

In the sample results, readings were taken using a digital thermometer with readings in degrees Fahrenheit at the top of each hour. Readings were taken from 08:00 to 19:00 hours. Before each reading the outside temperature was recorded. Visual notes on weather conditions were made. All temperatures were converted to Celsius.

The collected data was analyzed using basic statistical methods and to examine the data for similarities, a t-test was incorporated to examine the differences, if any. The comparisons of the temperatures are presented in their entirety and as averages. These temperatures are compared to that of the recorded temperature of 52 degrees Celsius. The results were entered into Excel and formulas entered to perform the basic analysis. The t-tests were performed using SPSS.

The studies were conducted over several days during August and early September of 2014. Six, day long tests were conducted to collect data and to record observations. The tests were conducted in the town of Barre, VT, USA, located at 44.1853° N, 72.4861° W at an elevation of 186 meters above sea level. The comparison system is located in Tubarao- SC, Brazil is located 7.00 meters above sea level at the coordinates 28.4667° S, 49.0069° W.

**Sample Operating Procedures and Processing Data**

As stated, the capability of piping materials to absorb and transfer collected solar heat to the liquids contained within the pipes is critical to the absorbers efficiency. This investigation is to determine the Solar Tubes performance compared to each other and to the limited results published by Mr. Alano. The descriptive statistics indicated an average daily temperature of 58.82 degrees Celsius and an average time of the day that the highest temperature was recorded was 13:25 hours. Average six day data set was statistically analyzed using t-tests for comparison of data; the results are presented in Table 1. All temperatures are presented in degrees Celsius. The results of the six tests are similar and show no difference.

Table 1 – Statistical Results for the Average Temperatures Per Test Tube

| One Sample Test | | | | | | |
|---|---|---|---|---|---|---|
| Test Value = 0 | | | | | | |
| | | | | | 95% Confidence Interval of the Difference | |
| | T | Df | Sig. (2-tailed) | Mean Temp (Celsius) | Lower | Upper |
| Tube 1 | 8.65 | 11 | .000 | 53.68 | 39.99 | 67.37 |
| Tube 2 | 9.84 | 11 | .000 | 63.57 | 49.31 | 77.83 |
| Tube 3 | 8.65 | 11 | .000 | 54.47 | 40.57 | 68.37 |
| Tube 4 | 9.91 | 11 | .000 | 63.57 | 49.41 | 77.72 |

Table 2 contains data indicating the percent increase in temperature from the daily mean temperature to the combination mean of the four Solar Tubes. Additionally, the percent increase is evaluated between Solar Tubes 1 and 2 along with 3 and 4. The increase in temperature between Solar Tubes indicates that tubes 2 and 4 perform slightly better than 1 and 3. The data also indicates that Solar Tube 2 with the painted background performed better than that of tube 4 with an unpainted aluminum background. Using the painted background not only performed better, but it is safer for students to install and the cost is reduced.

In reiteration, Solar Tubes 1 and 3 contain a CPVC pipe painted matte black utilizing PET bottles for glazing without any aluminum cans. In contrast, Solar Tubes 2 and 4 were similarly constructed with the exception that the pipe is encapsulated by aluminum cans painted a black matte finish. Lastly Solar Tubes 1 and 2 were mounted on a frame bed painted white as a reflecting surface whereas Solar Tubes 3 and 4 were mounted on a frame bed covered with aluminum for reflection of thermal energy.

Table 2 – Efficiency Levels of Solar Tubes Comparing the Mean Daily Temperatures to the Mean Temperatures Measured from each Solar Tube and the Efficiency between the Backing Material and the Solar Tubes

| Comparative Data | | | | | |
|---|---|---|---|---|---|
| Test Date | Mean Daily Temperature (Celsius) | Mean Temp of all Solar Tubes Combined (Celsius) | Multiplier Between Mean Daily Temp and Mean Temp of Solar Tubes | Average Temp between Tube 1 to Tube 2 | Average Temp between Tube 3 to Tube 4 |
| 24 Aug 14 | 25.56 | 59.00 | 2.31 | 16 | 10 |
| 26 Aug 14 | 25.56 | 59.78 | 2.34 | 35 | 12 |
| 01 Sep 14 | 27.33 | 62.39 | 2.28 | 30 | 13 |
| 02 Sep 14 | 27.50 | 63.96 | 2.33 | 13 | 12 |
| 04 Sep 14 | 23.06 | 55.33 | 2.40 | 21 | 21 |
| 07 Sep 14 | 17.78 | 56.22 | 3.16 | 17 | 17 |

## Assessment

The comparison of the four Solar Tubes served several purposes. The first was to examine which of the two backings, one pained white and the other covered with aluminum, would perform better. Secondly, with the addition of the painted cans would there be an increase in the collected heat.
Lastly was to preserve the integrity of Mr. Alano's idea of using recyclable materials to reapply them in a different manner from their original intent to create or capture the sun's energy. The average temperature of 59.45 degrees Celsius was collected between all the Solar Tubes and the six days data was collected during. The International Plumbing Code (IPC) requires that domestic water heaters are set at 60.00 degrees Celsius[8]. The average temperature was within 0.0092 percent of the IBC's requirements. On an average the addition of the aluminum cans increased the system by 18 percent.

In each statistical measurement of the collected data, the degrees of freedom, the t-test results and the significance level (P-values) (a cumulative data table is presented in Table 1) are within the prescribed ranges to determine that there is statically no difference between the various temperatures. The additional descriptive statistics were to examine if there were miniscule differences to justify which type of backing is needed and if the application of the cans assisted in collection of solar radiation to provide a greater efficiency to the system. The average Solar Tube, as stated, was 59.45 degrees Celsius, this surpassed the figure that Mr. Alano achieved of 50 degrees Celsius. Given that Solar Tubes 1 and 3 only had the CPVC pipe running through the

PET bottles, the average temperatures of the six data collection dates all surpassed the 50 degrees Celsius average that was achieved using the recycled cartons as a collector plate. This also indicates that the tubing material does not have to be in contact with the collector plate to achieve an efficient level. In examining the results from Solar Tubes two and four, which the pipe used the aluminum can as an absorber plate, the data was improved by 2.82 percent above the ambient temperature readings.

Figure 5 depicts the average temperatures of the six temperature readings. The graph shows the performance of the Solar Tubes. The Solar Tubes that incorporated the aluminum cans (Solar Tubes two and four) performed better than those without (Solar Tubes one and three). Further examination of the graph and the statistical results indicate that there is almost no difference between any of the Solar Tube configurations. This same logic is applied that there is no difference between the differing backings. These conclusions are in relationship to the known temperature of the system installed in Brazil. Also depicted is the average daily temperature during the test period. The average temperature in relation to the functionality of the four different Solar Tubes and backings is indicated by the daily temperature readings.

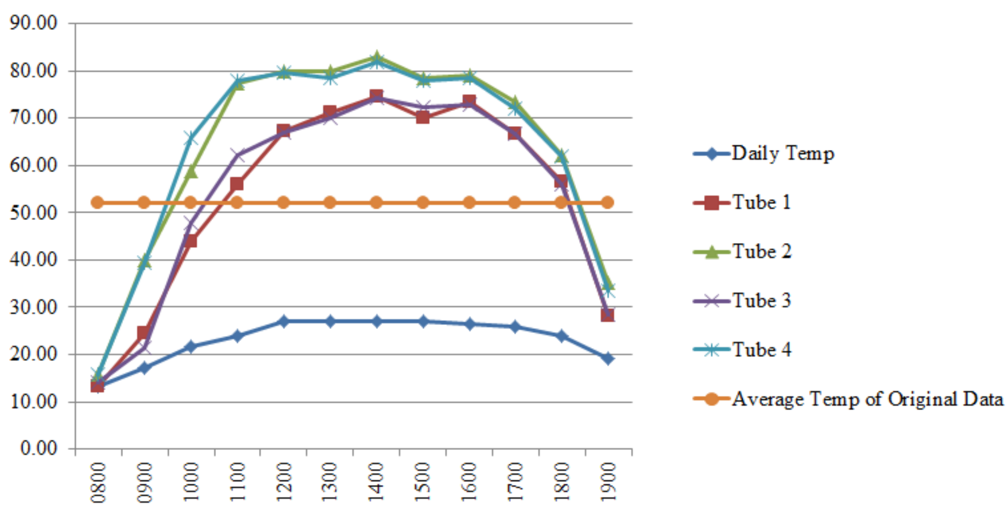


Figure 5: Average Temperatures Graph

## Conclusion

The results of this research will assist in the design of future water heater collectors used by students in a lab setting. The cost implication for the different variations is an important consideration. Lower construction costs will entice a larger following to explore solar water heating. The solar irradiation factor in the test area is lower than that of Tubarao- SC, Brazil, yet the results following the variations improved the temperature absorption. The conclusion drawn is the variations did succeed in increasing the efficiency of the system. The results of the research are to provide data that will aid in the decision-making process in the design and construction of DSWH using recycled materials by cross disciplinary teams.

Given the test apparatus' varied from the original design of Mr. Alano, the alternate apparatus' performed equal to or better than the original design. Contrary to the differences in the construction methods and materials they all four performed in a manner that statistically there is no difference. In that the experimental systems performed equal to or greater the research shows that the system can be improved. The addition of a backing material provided two distinct advantages. First it provided support to the Solar Tubes allowing for their length to be increased thus the collector area takes less room to install the system. Secondly, the examination of the data indicates that the reflective backing out performs the cardboard inserts used in the original design, thus assuming that there is an advantage to a 360 degree collection system. The increase in temperature between the Solar Tubes with the aluminum cans inserted is a substantial difference, thus the cans are an important aspect of the test design. Lastly, there is no difference between the painted backing and the use of aluminum backing. The cost of painting the backing is significantly less in materials and labor.

## Future Research

Given the results of the data collected and the students future research, future student research will be to build a full size collector. Multiple interconnected Solar Tubes are used in a thermosiphon system. A basic purposed collector design is presented in Figure 6. In the event of roof mounting it is necessary to ensure that the structure is able to support the additional weight of the collector and the water in the system. The angle of the system will also have to be considered in the design depending on the latitude of the installed system. The system will consist of eleven Solar Tubes the same length as those tested feeding into a recycled fifty gallon water heater storage tank. The system will consist of 11 Solar Tubes with 1/2" CPVC pipe on the interior of the tubes to move the fluid. At the top and bottom there is a 3/4" CPVC header angled to allow the water to flow properly in the thermosiphon system.

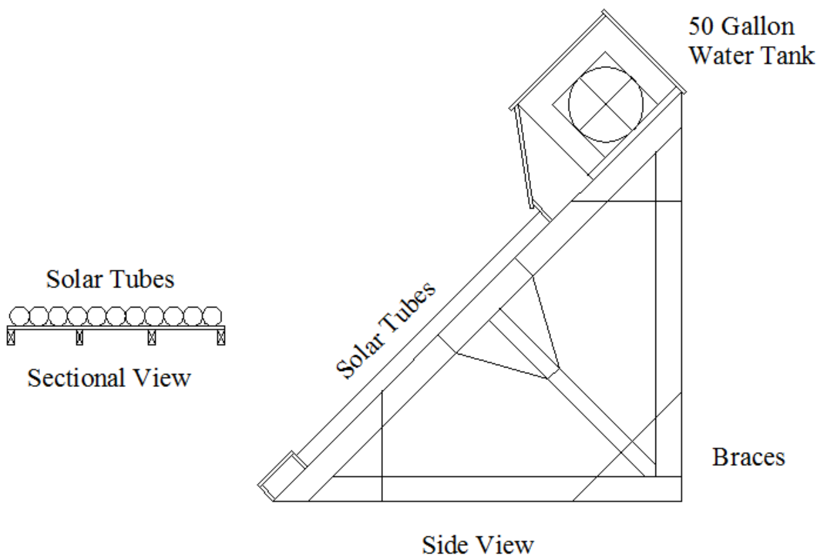


Figure 6: Full Scale Test Collector

The estimated cost of the full collector is $155.00. This is presuming that the materials used in the construction of the solar heater are collected at no cost from various sources. The wood could be collected from a contractor's waste bin and the 50 gallon tank is a recovered water heater that is cleaned and painted matte black.

## References


1 Solar Energy Industries Association (SEIA). (2014). Solar Heating and Cooling. Retrieved from http://www.seia.org/policy/solar-technology/solar-heating-cooling
2 Wilson, P. (2012). Doing the Math on Solar Water Heaters. Retrieved from http://www.americanthinker.com/2012/06/doing_the_math_on_solar_water_heaters.html
3 Alano, J. (2004). Manual on the Construction and Installation; Solar Heater Made of Disposable Packaging. Retrieved from http://www.builditsolar.com/Projects/WaterHeating/Construction%20and%20Installation%20of%20Water%20Heater.pdf.
4 Patterson, J. &Miers, R. (2009). The Thermal Conductivity of Common Tubing Materials Applied in a Solar Water Heater Collector. Associated Schools of Construction. 46th ASC Annual International Conference: Wentworth Institute of Technology, Boston, Massachusetts, April 7-10, 2010
5 Markell, L. G., & Hudson, J. (1985). *Solar Technology*. Reston, Virginia, USA: Ruston Publishing Company, Inc.; A Prentice-Hall Company.
6 NREL. (2014). National Renewable Energy Laboratory. Retrieved from http://www.nrel.gov/
7 Solar Isolation. (2012). Solar Isolation. Retrieved from http://solarinsolation.org/
8 IPC (2009 International Plumbing Code). (2009). Chapter 5, Water Heaters. International Code Council, Inc.: Country Club Hills, IL


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# A real-time simulator of a photovoltaic module

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## Abstract

In order to improve the efficiency of the photovoltaic system, converters and inverters with maximum power tracking are developed to get the maximum power since the PV systems are passive power source and their outputs are affected by the external load. However, in order to develop and test of these power electronics, current-voltage curve of the PV module should be controllable. This is not possible due to the fluctuation of solar insolation and temperature. In this work, a PV module simulator is designed and tested to generate power output and it can work in two modes: constant condition (solar irradiance and temperature) mode and real-time condition (real-time weather conditions and solar position) mode. This simulator consists of four modules: weather condition collection, solar position calculation, insolation calculation, and solar module. The solar module interacts with the other three modules and also one physical instrument, a programmable DC power source. In addition, a LabVIEW program is developed to process the information, monitor system, and control the output. Through the testing, the output voltage and current from the simulator follow the current-voltage curves in the two modes. Therefore, the simulator can be widely used to replace a real PV module for the development of MPPT converters and inverters.

**Key words**: renewable energy, PV module, maximum power point tracker, converter, inverter

## 1. Introduction

PV module price has fallen 75% to below $1/w since 2008 [1, 2]. There are over 17,500 MW of cumulative solar electric capacity operating in the U.S., enough to power more than 3.5 million average American homes, 36%, over 49,000 installations, of all new electric capacity is from solar in Q3 2014. It means that a new solar project has been installed every 3 minutes. The growth of solar industry boosts the economy and creates 174,000 jobs in the U.S. [3]. As a part of PV system, module-level, string, and central power electronics are well developed and the market for global PV micro-inverters and power optimizers will more than triple in the coming years, rising to more than $1 billion in 2018. The development and testing of the power electronics needs to input solar energy to be controllable, so the output PV module follows one current-voltage curve. This is hard to get from a real PV module [4].

In order to maintain this growth and meet the future demands of this industry, a skilled workforce is necessary. Therefore, solar-energy related courses are offered by more and more universities. In the education, especially in some experiments, it is hard to repeat results since weather significantly affect the PV system. Some labs may have to be cancelled in the Spring semester for the bad weather.

In order to facilitate the power electronics development and solar energy education, a system is needed to simulate the output from a PV module and the output from this system should follow the typical current-voltage curves of a PV module. In this paper, a simulator is developed with a programmable DC power source, which is controlled by the programs. The inputs to the simulator are zip code, date, and time. The orientation of the PV module can also be specified. The simulator can operates in two modes: constant solar irradiance and temperature mode, real-time solar irradiance and temperature mode.

## 2. System

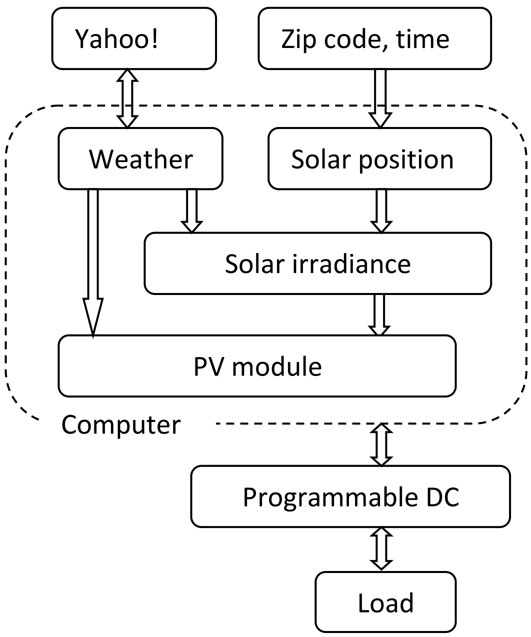



Figure 1 The structure of the PV module simulator

Figure 1 shows the structure of the system. The inputs include the zip code, date, and initial time. The output is the power to the load. The software controlling the system includes four modules: the weather module, the solar position module, the solar irradiance module, and the PV module. The power output generated is from programmable DC power source which communicates with the software.

The structure in Figure 1 is implemented as a program in LabVIEW with the front panel as in Figure 2. The system can run in two modes: real-time weather and constant weather. In the first mode, the system power output is affected by the local weather. While in the second one, the solar irradiance is set as any constant.

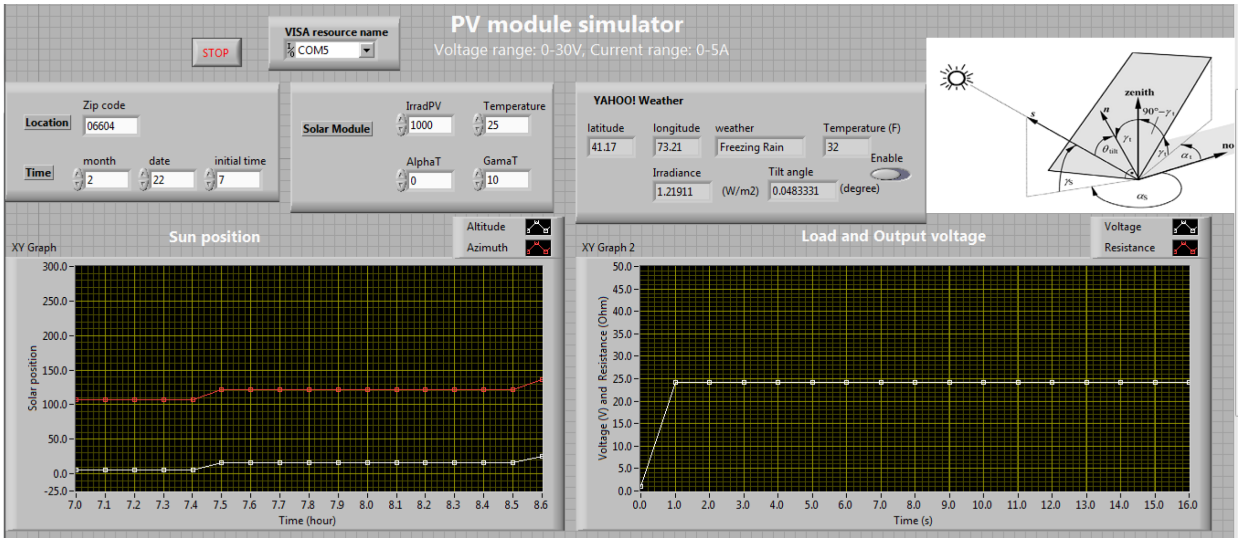



Figure 2 The front panel of the LabVIEW program

## 2.1 PV module

The PV module simulated in this work is close to real one, Ameresco Solar BP 90 Watt [5], and the characteristic data under different irradiance is shown in table 1 and the temperature coefficients in table 2.

Table 1 Characteristic parameters of the PV module

| Irradiance ($w/m^2$) | $V_{oc}$ (V) | $I_{sc}$ (A) | $V_{mp}$ (V) | $I_{mp}$ (A) |
|---|---|---|---|---|
| 1000 | 22.1 | 5.21 | 17.9 | 5.03 |
| 800 | 21 | 4 | 17.5 | 3.5 |
| 600 | 20.5 | 3 | 17.5 | 2.5 |
| 400 | 20 | 2 | 17.5 | 1.5 |
| 200 | 19 | 1 | 17.5 | 0.7 |

Table 2 Temperature coefficient

| | %/°C |
|---|---|
| Voc | -0.36 |
| Isc | 0.105 |
| Vmpp | -0.408 |
| Impp | -0.0281 |

The equation of the IV is:

$$I = I_{sc} - A(e^{BV} - 1)$$

Where, A, B, and $I_{sc}$ vary with solar insolation or irradiance. Linear interpolation is used to get the IV curve under irradiance.

The temperature effect on the module is considered in the following equation,

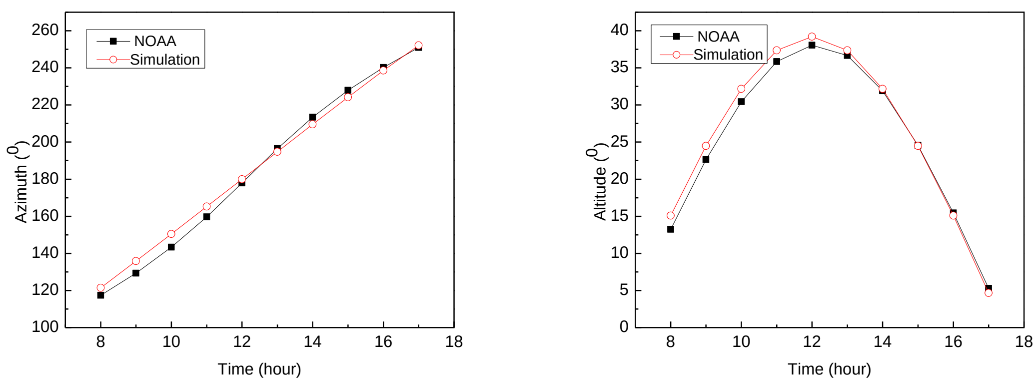
$$X_{ambient} = \left[\alpha\left(T_{STC} - T_{ambient}\right) + 1\right] X_{OC,rated}$$

Here, α is a temperature coefficient from table 2 and X is open-circuit voltage, short–circuit current, voltage at MPP, or current at MPP.

### 2.2 Weather

The real time weather condition is obtained through Yahoo! Weather RSS Feed [6]. The information from the XML file of Yahoo! includes weather, temperature, wind, and weather forecast. The weather condition affects the solar irradiance and the temperature affects the PV module output. Thus, both of them are the inputs to the Solar Irradiance and PV module in Figure 1.

### 2.3 Solar position




(a) (b)

Figure 3 Azimuth (a) and solar altitude (b) on Feb. 20, 2014[7]

The solar position is calculated based on the local altitude and time through Julian Day, declination angle, and hour angle. Figure 3 shows the comparison of the solar altitude and azimuth between the calculation and the data from National Oceanic and Atmospheric Administration (NOAA). This comparison indicates that the calculation is quite close to the one from NOAA.

## 3. Results and discussion

The hardware, in the system implementation and testing, includes a Programmable DC Power Supply (BK Precision 1788 with voltage range 0-32V and current range 0-6A) and a Programmable DC Load (TekPower 3711A). Since the voltage and current are unstable when the load from the Programmable DC load is less than 4Ω, 10W ceramic resistors are used.

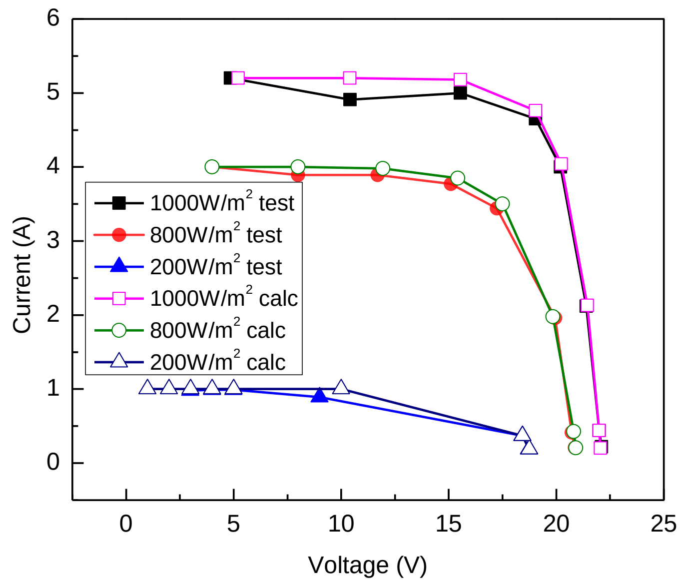



Figure 4 The current-voltage curves from the system and calculation under different irradiance

Figure 4 shows the current-voltage curves from the system and the calculation under 1000, 800, and 200 W/m$^2$. As the solar irradiance drops, the IV curve shifts to the lower left. The pairs of curves indicate that the real output is close to the one from calculation.

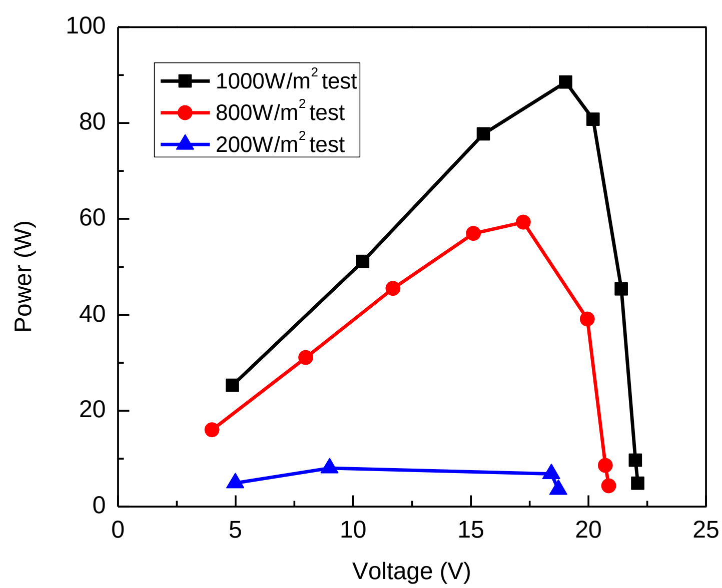



Figure 5 Power output under different irradiance

Figure 5 shows the experimental power-voltage curves under 1000, 800, and 200 W/m$^2$. On each curve, there is a maximum power point and this point drops from 90W to around 10W as the irradiance decreases from 1000W/m$^2$ to 200W/m$^2$. Thus, the system can be used to test power electronics, such as maximum power point trackers, converters, and inverters.

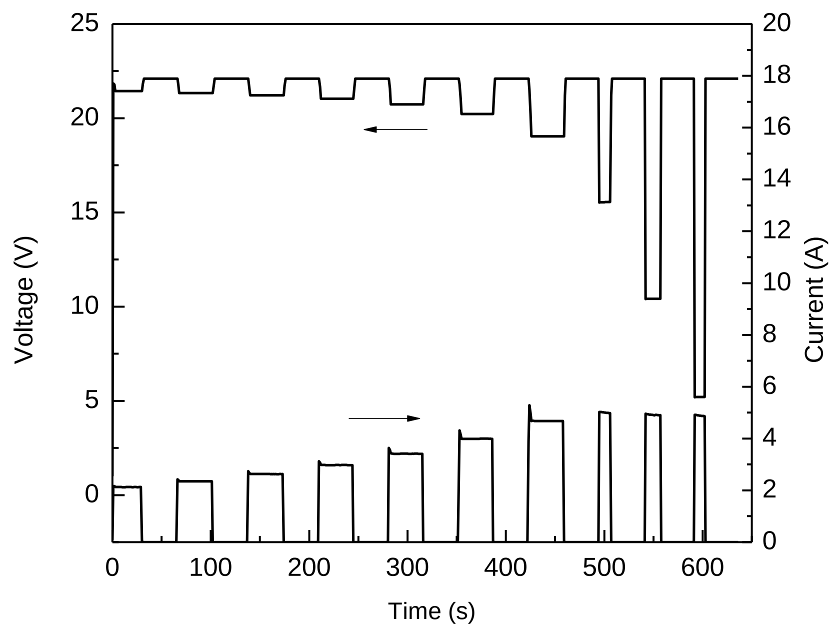



Figure 6 The voltage and current outputs at irradiance 1000w/m$^2$

Figure 6 is the dynamic response from the system as the resistance decreases from 10Ω to 1Ω. Here, the sampling time is one second. The response is relatively short and the maximum overshoot is 11%.

## 4. Conclusion

The simulator can generate power with the current-voltage characteristics as a real PV module with maximum power points under different solar irradiances. It can be used for the development of maximum power point trackers, converters, and inverters. More tests will be done on the response time and overshoot.

## References


1. Arnaud de La Tour, M.G., Yann Ménière, Predicting the costs of photovoltaic solar modules in 2020 using experience curve models. Energy, 2013. **62**: p. 341-348.
2. Liebreich, M., Investment, infrastructure & innovation for green growth. Bloomberg New Energy Finance, 2012.
3. Solar Energy Industries Association, Q3 2014 SMI Fact Sheet. 2014.
4. Minwon Park, I.-K.Y., A Novel Real-Time Simulation Technique of Photovoltaic Generation Systems Using RTDS. IEEE TRANSACTIONS ON ENERGY CONVERSION, 2004. **19**(1): p. 164-169.

5. http://www.altestore.com/store/Solar-Panels/Ameresco-BP490J-90W-12V-Solar-Panel-with-J-Box/p10175/.
6. http://weather.yahooapis.com.
7. http://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html.

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# Preparation of Nano-Particulate Magnetic and Dielectric Oxides via Co-precipitation Using Various Chloride Sources

**Patrick Doherty/University of Southern Maine, Kelsey Maguire/Bowdoin College, James Masi/University of Southern Maine, Deedra Zeeh/University of Southern Maine**

## Abstract

Magnetic and dielectric oxides ($Fe_2O_3$, $BaTiO_3$, FeO, ZnO, etc.) based nanoparticles have become a centerpiece for research in the scientific community over recent years. This work was conducted with the intent of developing a nano-particulate variable Fe, Ni, Zn, Mn, Ba, Ti oxide chemistry which was easy to implement at low temperatures in the lab/classroom, and which is not tied to high temperature fabrication methods and phase considerations (metastability). This was accomplished by using a metal chloride approach involving the eventual oxidation of individual and combinatorial variations on the abovementioned oxides.

The initial tests were made by fabricating both inductor cores and planar capacitors, calculating their magnetic permeability and permittivity, and their loss tangents at frequencies up to 1.8 GHz. The nano-particulate powders were properly suspended via wetting agents to keep the particles from aggregating. They were then pressed into toroids and plates and tested for both magnetic properties and dielectric properties. The simplicity of the methods makes implementation and understanding possible in both secondary and post-secondary labs. The cross-disciplinary areas of physics, biochemistry, and materials science enhance learning.

## Keywords

Ferrites, dielectric oxides, semiconductive oxides, nanoparticles, magnetic properties, dielectric properties.

## Overview/Background

Metal oxide ($Fe_2O_3$, $BaTiO_3$, ZnO, $Al_2O_3$, etc., and combinations) based nanoparticles have always attracted the attention of scientists from many fields. The potential applications for these nanoparticles cover many fields including the energy, mechanical, biomedical, magnetic, catalysis, and electrical areas, to name a few. Magnetic particles have already been used in medical imaging/therapy and information storage, and nano-sized particles may offer unique or improved properties [1], [2]. For example, magnetic nanoparticle contrast agents may improve contrast between healthy and diseased tissue in magnetic resonance imaging (MRI). Dielectric nano-particles can be used in the preparation of capacitors and insulators. Semiconductive nano-particles can be used in the preparation of electronic and display devices. The prepared nanocrystals could have potential in environmental and biomedical applications (such as in targeted drug delivery).

There are a number of methods for producing nano-particulate oxide particles, among which are:

1. Metal chloride reaction with sodium hydroxide;
2. High temperature calcining of carbonates;
3. High temperature hydrothermal growth [1];
4. Nitrate/hydroxide reactions, thermal or microwave [2];
5. Glycerol and Sodium dodecyl sulfate assisted ferrite reactions; and
6. "Ferrofluid" methods using various carboxylic acids or poly acrylic acid formulations [2].

Many of the approaches for synthesizing superparamagnetic iron oxide nanocrystals require complex processes and the use of toxic materials. This study used a co-precipitation method that follows the green chemistry principle (environmentally friendly and economical) to prepare superparamagnetic iron, dielectric oxides, and mixed oxide nanocrystals.

This part of the work was conducted with the intent of developing a nano-particulate (variable composition) Fe, Ni, Zn, Mn, Ba, Ti oxide (e.g. $Mn_{0.67}Zn_{0.33}Fe_2O_4$, manganese-zinc ferrite and $BiTiO_3$, barium titanate) chemistry which was easy to implement at low temperatures in the lab/classroom, and which is not tied to high temperature fabrication methods and high temperature phase considerations (metastability).

**Size effects on melting points of nanoparticles**

Nanoparticle "inks" contain particles that are extremely small within 1~100nm range, a collection of about 100 atoms. Nanoparticles cannot be observed with the naked eye; the ultra fine particles that are visible to the naked eye are in fact coagulated nanoparticles. When heated up to the temperatures far below the melting points of bulk material, the nanoscale particles essentially weld themselves together, forming a rigid network of magnetic, conductive, or dielectric ink. Size effect on the melting points of tiny particles is the main theoretical basis for nanoparticle ink.

Pawlow improved the Gibbs-Thompson model by considering the equilibrium of a liquid spherical drop with both a solid spherical particle of the same material and its vapor. This model leads to the following well-known equation:

$$\frac{T_\infty - T}{T_\infty} = \frac{2}{\rho_s L_{sv} R_s}\left[\gamma_{sv} - \gamma_{lv}\left(\frac{\rho_s}{\rho_l}\right)^{2/3}\right],$$

where $\rho_s$ is the density of the solid phase

$\rho_l$ is the density of the liquid phase

$L_{sv}$ is the latent heat for the solid-vapor phase transition

$R_s$ is the radius of the sphere solid region

$\gamma_{sv}$ is the solid vapor interfacial energy

$\gamma_{lv}$ is the liquid –vapor interfacial energy

$T_\infty$ is the bulk melting temperature

$T$ is the small particle melting temperature.

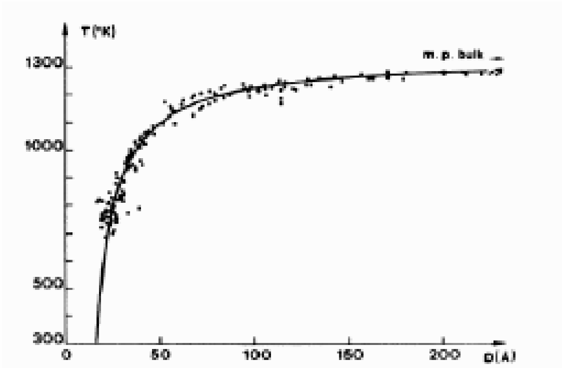



**Table 1. Size effects on the melting points of gold particles.(Pawlow)**

It is for this reason that the ferrite and dielectric oxide nano-particles actually nucleate and grow at much lower temperatures than their bulk melting points.

NOTE: Melting points of ~80-100 nm ferrite and dielectric ZnO particles were observed to be 420 and 370 C respectively. More work is needed.

## Methods /Materials

### Ferrofluid Methods

The evolution of methods for nanoparticle production is shown below in Figure 1.

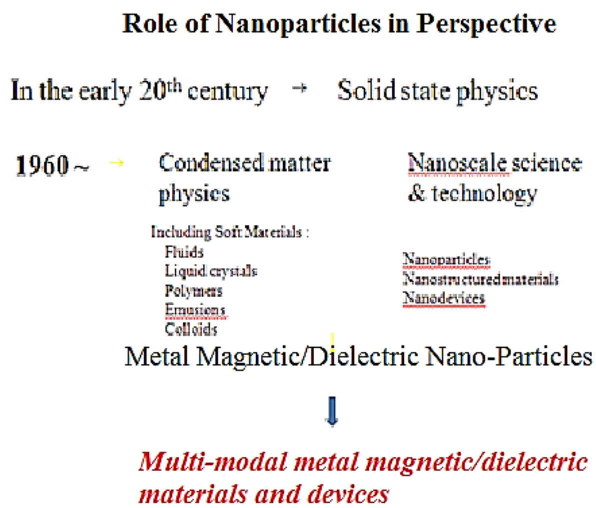



**Figure 1. Fluid fabrication evolution method**

Initially, to produce the ferrite, we followed a standard process [2]. In this process, 10 milliliters (mL) of both PCB etchant and distilled water are combined. Steel wool is added to the solution until a complete color change and reaction occurs. Grade one filter paper is used to filter the larger steel wool particles out of solution. The filtered solution should be green; this is ferrous chloride ($FeCl_2$). Then, 20mL of PCB etchant (which is ferric chloride, $FeCl_3$) are added to the green filtered solution. This sets up the ratio of $FeCl_2$ to $FeCl_3$ for the proper reactions (see below) to take place.

The next step involves adding 150mL of ammonia solution (10% by weight $NH_4OH$) to the ferric chloride/ferrous chloride mixture, which causes $FeO{\cdot}Fe_2O_3$ to precipitate out. The chemical equations for this process/reaction (rxn) are as follows:

Rxn 1: $FeCl_3(aq) + 6NH_4OH(aq) \rightarrow Fe_2O_3(s) + 3H_2O(l) + 6NH_4Cl(aq)$, $\Delta H_{rxn} = -204.13$ KJ/mol-rxn

Rxn 2: $FeCl_2(aq) + 2NH_4OH(aq) \rightarrow FeO(s) + H_2O(l) + 2NH_4Cl(aq)$, $\Delta H_{rxn} = -8.55$ KJ/mol-rxn

Rxn 3: $FeO(s) + Fe_2O_3(s) \rightarrow FeO{\cdot}Fe_2O_3(s)$, $\Delta H_{rxn} = +79.5$ KJ/mol-rxn

Combined Rxn: $FeCl_3(aq) + FeCl_2(aq) + 6NH_4OH(aq) \rightarrow FeO{\cdot}Fe_2O_3(s) + 4H_2O(l) + 8NH_4Cl(aq)$, $\Delta H_{rxn} = -133.18$ KJ/mol-rxn

The combined reaction occurs readily and spontaneously in the ammonia solution. The solution is heated to just below boiling, and the surfactant is applied. In order to keep the nanoparticles from colliding and aggregating, oleic acid is used as a surfactant. Oleic acid is a long carbon chain with a carboxylic acid group (-COOH) at one end (Figure 2). The carboxylic acid group contains a highly polar oxygen-hydrogen (O-H) bond which causes a small partial charge to be induced on both the oxygen and hydrogen atoms. This polar head forms a weak bond to the nanoparticles before they can aggregate. When several of these oleic acid molecules surround a nanoparticle, it forces any others away from it. The distance that the oleic acid pushes the nanoparticles away from each other causes some abnormal magnetic effects in the material.

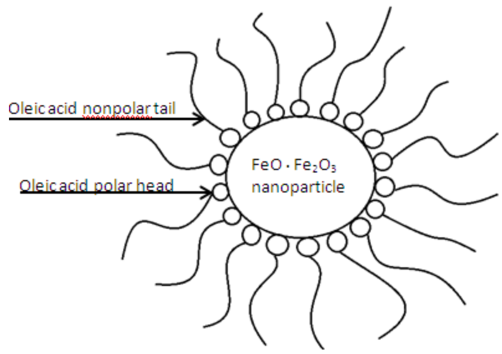



**Figure 2. Oleic acid (or other surfactant) surrounding ferrite nano-particle**

When a magnetic field passed through a normal aggregate iron oxide mass, each cell in the crystal structure would induce a magnetic field on the adjacent cells and there would be a chain reaction in the structure. In the case of nanoparticles, a magnetic field causes each one to react independently instead of the particles around it influencing its induced field. In an ideal situation, the surfactant coated nanoparticles would each behave as an independent magnetic particle.

Solutions of ferric and ferrous chloride can also be reacted directly [3] in the presence of a base (sodium hydroxide) can also be used to form iron oxide nanocrystals. However, the resultant reaction products have a tendency to contaminate the nano-particles. Polyacrylic acid can also be used as a surfactant to stabilize the particles.

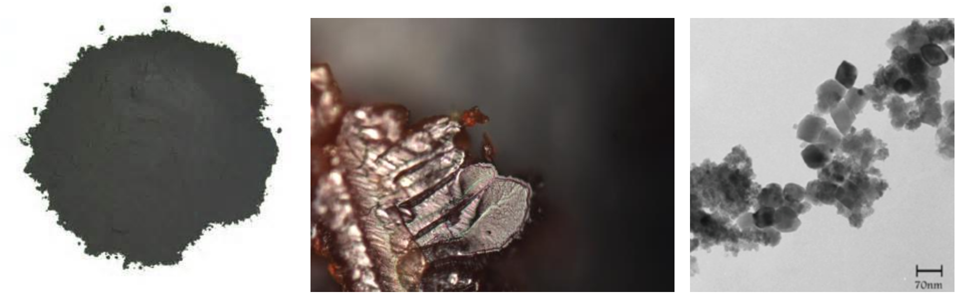
By using the chlorides of Fe, Ni, Zn, and Mn, iron oxide, $FeO{\cdot}Fe_2O_3$, with varying Ni, Zn, and Mn substitutions for the divalent Fe, can be formed. Hence, the mixed ferrite can be formed. Other metal chlorides may be substituted in for the ferrous chloride ($FeCl_2$) as long as they are divalent metals

- i.e. $ZnCl_2$, $NiCl_2$, $CuCl_2$, $MnCl_2$, etc.
- Note: They may also be included in addition to the ferrous chloride

  $4FeCl_3 + FeCl_2 + NiCl_2 + 16NH_4OH \rightarrow FeO{\cdot}NiO{\cdot}Fe_2O_3 + 8H_2O + 16NH_4Cl$
  (approximation of reaction**?????**)

The direct synthesis using $FeCl_3$ with Ni-, Zn-, $MnCl_2$ is easier and easier to control agglomeration of the nano-particulates. Ammonium hydroxide, leaves a removable (evaporation) ammonium chloride product.

Some interesting air baked (80$^{o}$C) samples and their dendritic patterns and directionality are shown in Figure 3.




**PowderAir Dried 50X   Fractal Branching?   Separated particles**

**.Figure 3.  Air dried ferrite samples and interesting morphology.**

It should also be noted that there is an optimal size for the particle to exhibit maximum coercivity without remnance (superparamagnetic behavior) as seen in Figure 4

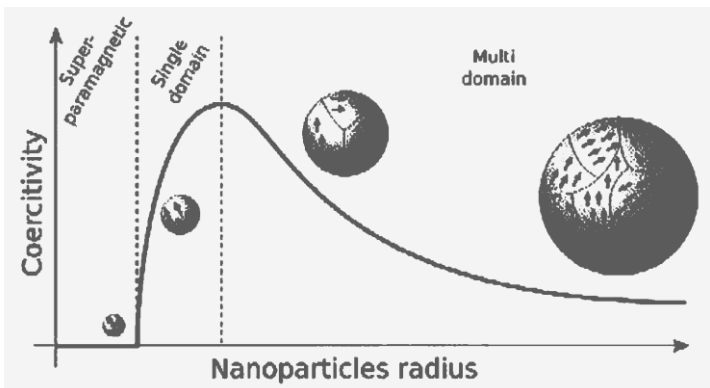



Figure 4.  Schematic illustration of the coercivity-size relations of small particles


**Figure 5.  ~20nm suspension of ferrite (left two pictures), Ni ferrite and roasted (5 hours) nano- Ni-Zn ferrite (right picture of powder), lower PAA surfactant**

## Applications of the Process

- Sandia Nat. Labs high frequency inductor program
- Hemoglobin increased oxygen uptake (iron 2 oxide only)
- Low temperature process (easy to do)
- High Curie temperatures (>150C) in polymer core
- Polymer →insulative (no eddy  current losses)
- Studies continuing on optimal loading in epoxy.

## Generalized Oxide Formation by Chloride Chemistry

Valence two metals form oxides (MeO) and combinations in a foreshortened fashion using their chlorides as detailed above.  Valence three metals form oxides ($Me_2O_3$) as easily and in combinations with other +2 and +3 oxides using the chloride chemistry.

For instance, ZnO, an interesting, wide-bandgap semiconductor (transparent in the visible region of the spectrum) and can be doped with a variety of materials, including Al, Mg, etc. using standard calculations for fractional additives with chlorides.  A typical thermodynamic balance calculation is shown below.

$ZnCl_2$ (aq) + 2 $NH_4OH$ (aq) = ZnO (s) + $H_2O$ (aq, of course) + 2 $NH_4Cl$ (aq)

Using the free energies associated with each of the compounds yields the right hand side with -100kJ/mole driving the reaction.  As found in previous work, the **higher the ratio of ammonium hydroxide to chloride, the smaller the particle size of the solid** (not a linear relationship…work in process).  i.e., the faster the reaction proceeds, minimizing the size of ZnO nuclei. Variation in size of ZnO particles with reaction speed is shown in Figure 6  Also show is a TEM photo of nanoferroelectric $BaTiO_3$ produced by a modified halide chemistry route. NOTE:  The titanates have a tendency to vary in crystal morphology.


(1) (2) (3)

Figure 6.  ZnO (1, 2 powder) and nanoferroelectric BaTiO3 (3) micrographs (Courtesy of USM, NIH and T K Kundu )

Typical capacitors are formed by mixing a slurry of polyurethane (10%) with ZnO or $BaTiO_3$ and coating, baking, and applying contacts as shown in Figure 7.

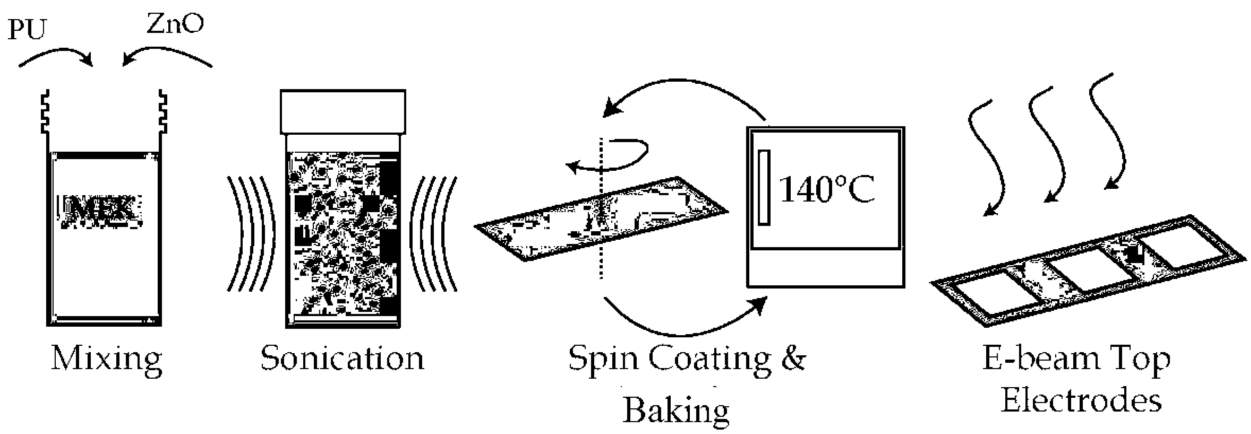
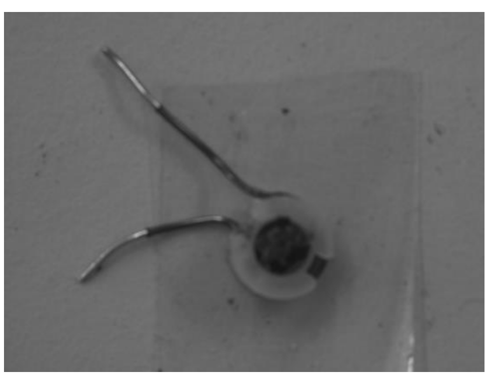
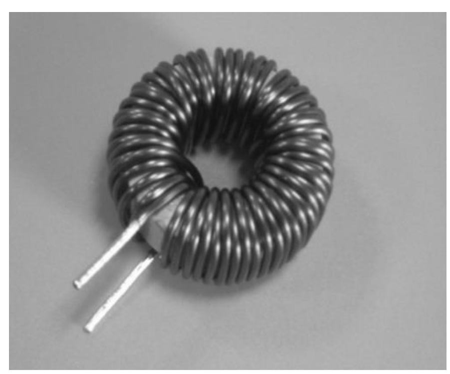



Figure 7. Typical fabrication of capacitors using oxide nanoparticles (courtesy WNEU, Kenneth J. Loh, UCal, Davis)

**Testing/Metrology**

Testing was performed on different samples of iron oxide nanoparticles and oxides of Zn, Ti, Ni, Mn and combinations of these processed in different ways, such as suspensions of these materials using anti agglomeration surfactants such as oleic acid and PAA, drying by rapid heating, gradual heating, and suspension in polymers as shown in Figure 8.





**Sandia National Laboratories inductor** **Nano ferrite toroid**

**Ni ferrite in60/40 nano/epoxy**

**Figure 8. Conformations of two types of nanoparticles tested**

Testing the inductor with these nanoparticle cores revealed in which direction we would go when creating toroids for experimental testing. Suspending the nanoparticle-surfactant complex into epoxy created a rigid structure that could be easily molded before drying and had strong normalizing effects on the Quality factor (Q) of the inductor. Measurements were made on a 0-

40 MHz HP Gain-Phase Impedance Bridge, an HP 5-1800 MHz High Frequency Materials analyzer, and a Walker High Frequency B-H tester (Figure 8). Loss tangent = tanδ= μ''/μ'.

**0-40 MHz HP Gain-Phase Impedance Bridge**

**High Frequency B-H tester**

**HP 5-1800 MHz High Frequency Materials analyzer**

**Figure 8. Test/Analysis equipment**

A B-H curve of one of the nano-ferrite/epoxy cores is shown below in Figure 9

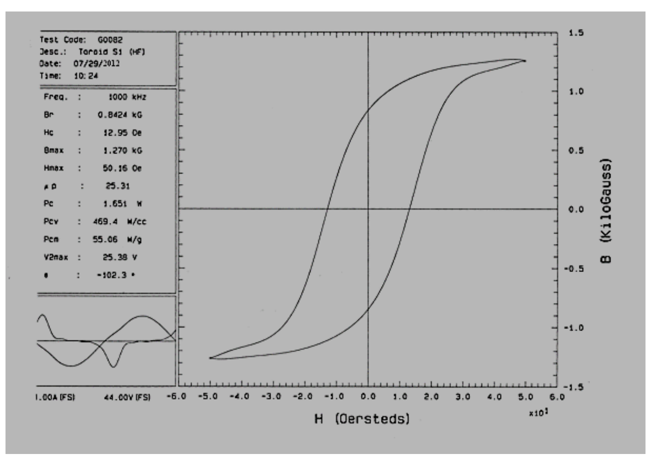



**Figure 9. B-H hysteresis loop for a material with μ~25**

The initial tests were made by fabricating inductor cores (both imbedded in epoxy and pressed into toroids with optimal magnetic properties, measurable in the laboratory for L, Q, and Z vs. frequency, from 100 Hz to 1.8 GHz. Using a ferric oxide ($Fe_2O_3$) base for the materials and varying levels of nickel, manganese, and zinc oxide, we have created several cores which reduce the loss tangent for the cores. For the sake of brevity, only the iron and nickel data are given in Figure 10.

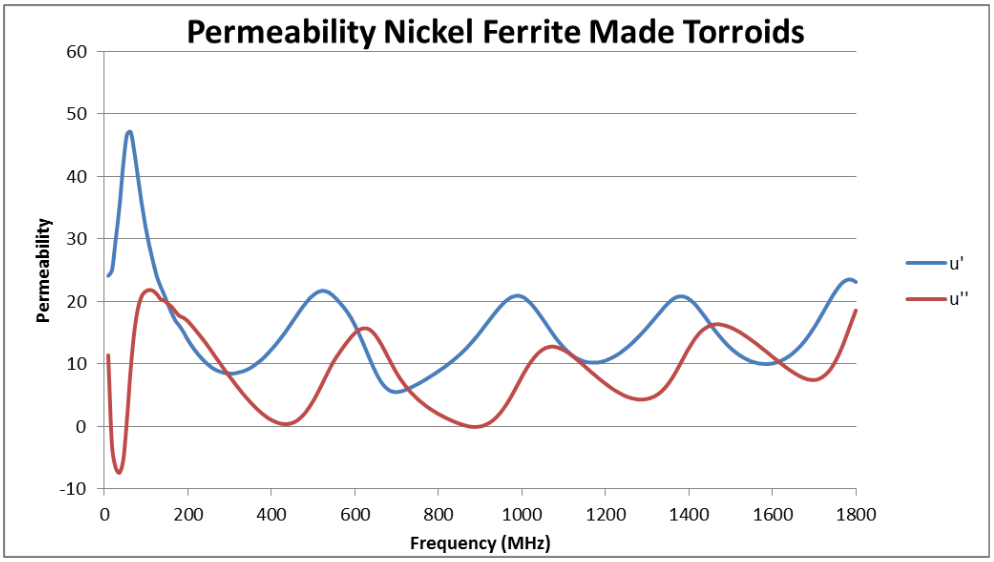



**Figure 10. Permeability and loss for various cores**

Capacitors were made using foil based square patterns of 1 and 28 mm on a side as shown in Figure 11..

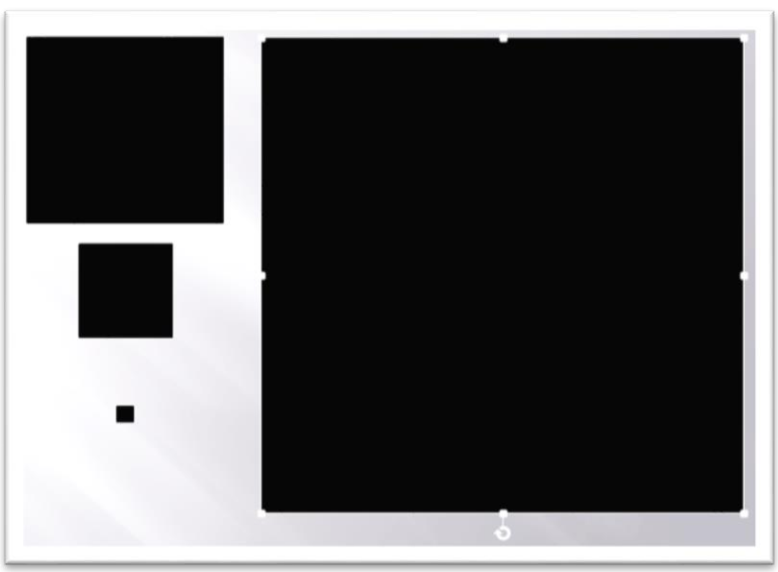


**Figure 11. Typical capacitor template**

Typical capacitance vs frequency for spun ZnO capacitors is shown in Figure 12.

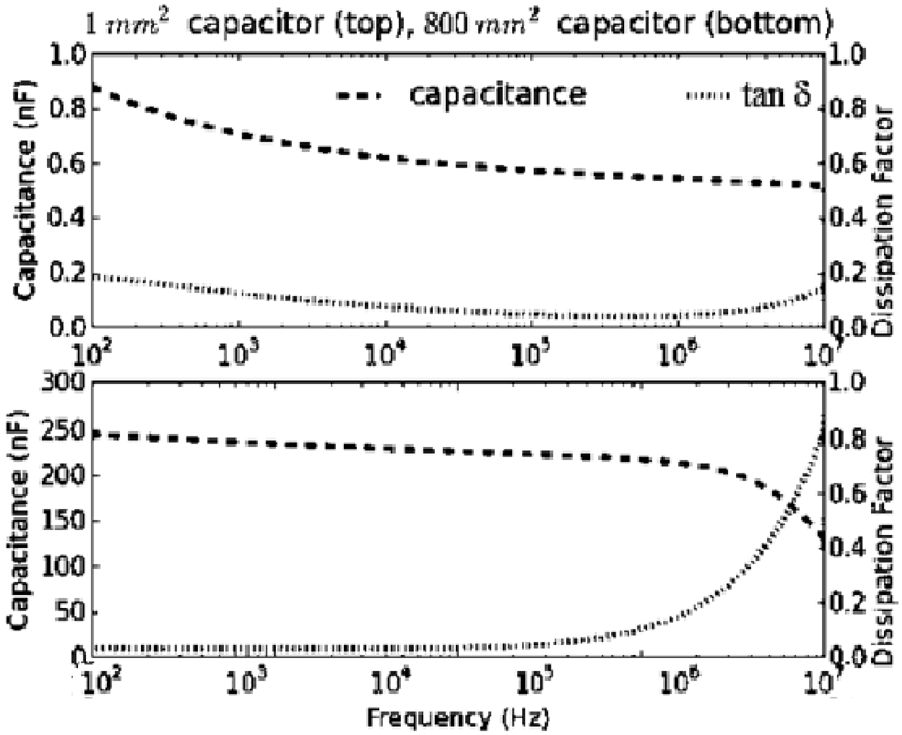



**Figure 12. Typical Capacitance and dissipation factor for 800:1 area ratio for nano particle spun capacitors**

## Conclusions

Magnetic and dielectric nano particulate oxides ($Fe_2O_3$, $BaTiO_3$, FeO, ZnO, etc.) based nanoparticles and combinations of these have been synthesized by low temperature chloride chemical means. By using iron oxide ($FeO \cdot Fe_2O_3$, with varying Ni, Zn, and Mn substitutions for the divalent Fe) nanoparticle cores, the behavior of the inductor can be altered, due to different magnetic properties of materials at the nanoscale versus micro/macro scale. In order to test the effect of nanoparticle cores on inductors, our process includes manufacturing the particles, designing a process for core production, testing the properties of the cores, and altering the chemical structure of the cores for optimal magnetic performance. Similar methods can yield nano particulate dielectric oxides (ZnO, $BaTiO_3$, $TiO_2$, etc.). By using a green, co-precipitate method, mixed ferrite, super-paramagnetic, and dielectric nano structured materials and low-loss devices can be formed at low temperatures.

We are investigating photocatalytic copper tungsten oxide nanoparticles (produced by the same green chemistry) to break down oil into biodegradable compounds. The nanoparticles are in a grid that provides high surface area for the reaction, is activated by sunlight and can work in water, making them useful for cleaning up oil spills. Work is in process to investigate these materials as well as the above mentioned dielectric and magnetic ones.

The simplicity of the methods makes implementation and understanding possible in both secondary and post-secondary labs. The cross-disciplinary Physics, biochemistry, and materials science backgrounds of the co-investigators serve as a learning experience for all.

## REFERENCES

[1] Doherty, P. Masi, J, and Zeeh, D., "Ferrites at room temperature: materials science, chemistry, physics, and metrology on tailored compositions", 2013 ASEE Northeast Section Conference, Norwich University, March 14-16, 2013

[2] Nejati, Kamellia and Zabihi, Rezvanh, "Preparation and magnetic properties of nano size nickel ferrite particles using hydrothermal method", Chemistry Central Journal 2012, 6:23

[3] Zhenyu, Lai, Guangliang, Xu, Yalin, Zheng, "Microwave assisted low temperature synthesis of MnZn ferrite nanoparticles", Nanoscale Res Lett (2007) 2:40–43.

[4] The procedure for the basic ferrofluid was due to Dr. John Bedell of Allied Signal in 1961 and later by: Enzel, Patricia; Adelman, Nicholas B.; Beckman, Katie J.; Campbell, Dean J.; Ellis, Arthur B.; Lisensky, George C. J. "Preparation and Properties of an Aqueous Ferrofluid". Chem. Educ. 1999, 76, 943.

[5] Plamthottam, Sheba S., Private communication, 2008.

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# Digital Controller Design and Implementation on a Buck-Boost Converter for Photovoltaic Systems

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## Abstract

A photovoltaic (PV) systems are widely used to convert solar energy into electricity. The output of PV system is strongly affected by the weather. In order to maintain the stability of the electrical power, a rechargeable battery is necessary to temporarily store the electricity. The objective of this paper is to make the output voltage of solar panel constant in order to connect its 12V DC rechargeable battery in order to determine whether a change occurred in the input voltage or load. In our proposal, MATLAB-Simulink used to simulate the feedback controller for the power stage, referred to as the Buck-Boost converter. In addition, the Arduino Uno was applied as a PID (proportional, integral, derivative) controller, and the tested while connected to the converter. The results from MATLAB-Simulation and the Arduino Uno experiments will be compared and analyzed.

## Keywords

Digital PID controller, Arduino Uno, Buck-Boost converter, Feedback controller, Photovoltaic system.

## Introduction

The photovoltaic system is a part of the renewable energy that has a great significance in future energy systems. Low fuel costs and low maintenance are the benefits of solar energy systems, Petrone, et al.[1]. However, PV modules still have a relatively low efficiency conversion. The output voltage of these modules remain unstable due to weather changes, and thus making them nonlinear systems. Therefore, DC to DC converters have been used to control PV output voltage, Abouobaida and Cherkaoui [2]. DC to DC converters are used in Buck, Boost, and Buck-Boost at varied input voltage levels. The Buck-Boost converter, which is known as an inverting regulator, is shown in Figure 1. It is step up/ down converter that allows the output voltage to be greater or lower than the input voltage by change duty-ratio D.

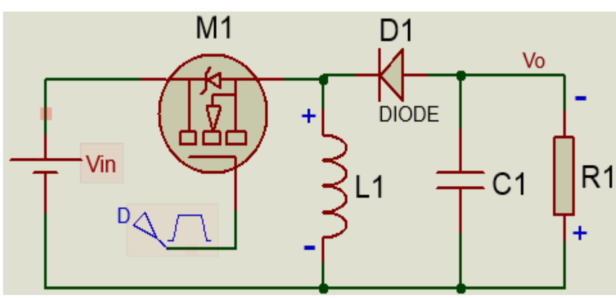



Figure 1: Buck – Boost converter

The output voltage depends on the duty cycle value, which goes from 0 to 1. Equation (1) shows the expression of the duty cycle of the Buck-Boost converter [3].

$$\frac{V_o}{V_i} = \frac{D}{1-D} \tag{1}$$

Where: $V_o$ is the output voltage, $V_i$ is the input voltage, and D is the duty cycle of power switches.

In order to get constant output voltage with minimum fluctuation, it is necessary to build a feedback circuit. There are many types of controllers that are used to diminish the oscillation of the converter output voltage such as P, PI, PD, PID, and fuzzy logic controller based on studies [4, 5]. The primary objective of those controllers is to control the duty cycle D in order to get the desired output voltage. In this paper, PID controller is utilized because it is possible to connect to a microcontroller such as Arduino Uno. The Arduino Uno can operate such a stand-alone device. PID controller has been used since the 1980s, to give a big jump to the process automation technology. Figure 2 shows the block diagram of PID controller with any system, where, all three $K_p$, $K_i$, and $K_d$ gains are connected in parallel. The error signal is considered the input of the PID controller.

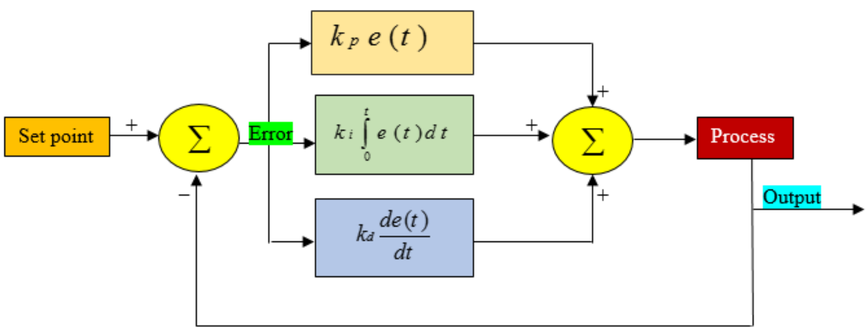



Figure 2: The block diagram of a PID Control

The PID control equation may be expressed in different ways, but an overall formulation is displayed in equation (2) [6].

$$u(t) = Kp\ e(t) + Ki \int e(t)dt + Kd\ \frac{de}{dt} \tag{2}$$

Where: $K_p$ is proportional gain, is $K_i$ integral gain, $K_d$ is derivative gain, e is the difference between the output voltage value and the set point t: time or instantaneous time.

**Modeling the Buck-Boost Converter with PID Controller**

MATLAB-Simulink program is a graphical tool that can utilize to make a model of a block diagram for simulation and continuous test. By using Simulink program, the Buck-Boost converter with PID control is developed in Figure 3. Also, the Parameters of Buck-Boost converter are inserted in Table 1. Parameters have been chosen as the same as Power Pole Board values, which is educational kit for the implementation stage to get the accurate theoretical and practical results.

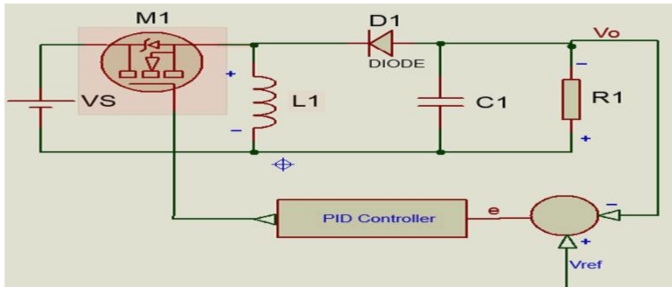



Figure 3: Buck-Boost converter with PID controller

| components | Vin (v) | R load(Ω) | L (μH) | C (μF) | set point (v) |
|---|---|---|---|---|---|
| Values | 9 | 20 | 100 | 697 | 12 |

Table 1: The Buck-Boost components

There are different possible techniques to find out the parameters of the PID controller. There are algorithm ways such as Genetic Algorithm and Bacterial Foraging Algorithm that can give accurate results. However, these two particular algorithms have the disadvantage of being slow to find out the PID parameters. Another method is PID manual tuning by using the Ziegler–Nichols tuning method that has an advantage of an online method and requires no math expressions. Another advantage of using the Ziegler–Nichols tuning method that it is an experimental way to tune a PID controller. This method was proposed by Jon Ziegler and Nichols in 1940s. In addition, it is achieved by setting I (integral) and D (derivative) gains to zero. The P (proportional) gain, $K_p$ is then increased (from zero) until it reaches the final gain Ku, at which the output of the control loop fluctuates with a constant amplitude [7]. Table 2 shows the control gain obtained from Ziegler–Nichols tuning technique.

| parameters | Kp (proportional gain) | Ki (integral gain) | Kd (derivative gain) |
|---|---|---|---|
| Values | 22.56 | 116 | 0.0253 |

Table 2: PID controller gains

After running the MATLAB-Simulink, the step response output voltage of the Buck-Boost converter with PID control is shown in Figure 4 where the output voltage is constant 12V.

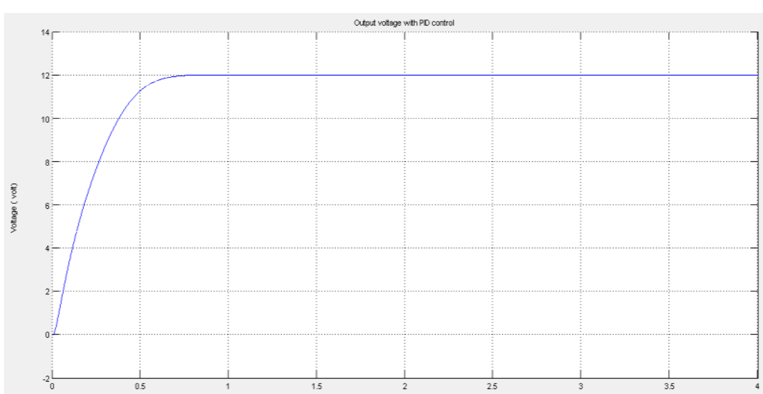



Figure 4: step response of output voltage of Buck-Boost converter

Moreover, the data of Check Step Response Characteristics block is used to catch on the characteristic of the output voltage that was recorded in Table 3 in order to find out rise time, overshoot, etc. Also, for more evidence, the output results are compared with results of the paper that is published by Rao, et al. [8].

| parameters | Rise time (sec) | Percent Overshoot (percentage) | Settling time (Sec) | PercentSettling (percentage) |
|---|---|---|---|---|
| values | 0.834 | 0.053 | 1.56 | 0.0019 |
| paper- GA | 0.0128 | 0.2092 | 0.0276 | 0.21 |
| paper-BFOA | 0.0129 | 0.2338 | 0.0204 | 0.74 |

Table 3: Comparison of results obtained from Ziegler–Nichols with GA and BFOA method

By looking at the step response characteristics table, the output voltage of the Buck-Boost converter taken 0.834 sec to reach the final value is 12 volt. The Table 3 shows overshooting of the signal is about 0.053% before settling time. However, the settling time start from 1.56 sec and the oscillation in the signal is 0.0019 % that is very small. The compassion clear demonstrations that the PID controller of GA and BFOA method is a faster response than our controller. However, our controller has less overshooting peak and more stability. That means there is no sudden jumping in current and slight swaying around the set point.

## Implementation of the PID Controller

To implement the converter with PID control, the Power Pole Board and the Arduino Uno are used. The Power Pole Board is an experimental kit that is used to execute different experiments in power electronic lab. In this paper, Power Pole Board is used such a Buck-Boost converter. On the other hand, the Arduino Uno, which is the open source microcontroller, is utilized such as PID controller. Afterward, the code of PID algorithm in equation (2) got written by using Arduino C language. It is then downloaded into Arduino microcontroller ATmega328 to make it work as a stand-alone device [9]. The maximum analog input voltage at Arduino Uno is 6 volts. Therefore, a voltage divider that is already provided by the converter board is used to make Arduino operation in a safe side. Reduced output voltage of the converter is connected to analog Arduino Uno pin A0. To make this project more beneficial, the potentiometer is connected to analog pin A1 in order to obtain a wide range of reference voltages. However, its limitation depends on input-output voltage restrictions of the converter board. The advantage of the Arduino board is that it can give direct PWM outputs. We could avoid using another piece for PWM generation. Thus, this PID controller is less expensive microcontroller. The whole circuit has setup in Figure 5. Also, the potentiometer, which is an adjustable resistor, has been installed where a set point can be chosen. Furthermore, 9 volt lithium battery is connected to Arduino in order to take advantage of Arduino that is its operation such a stand-alone controller without using a PC-USB interface.

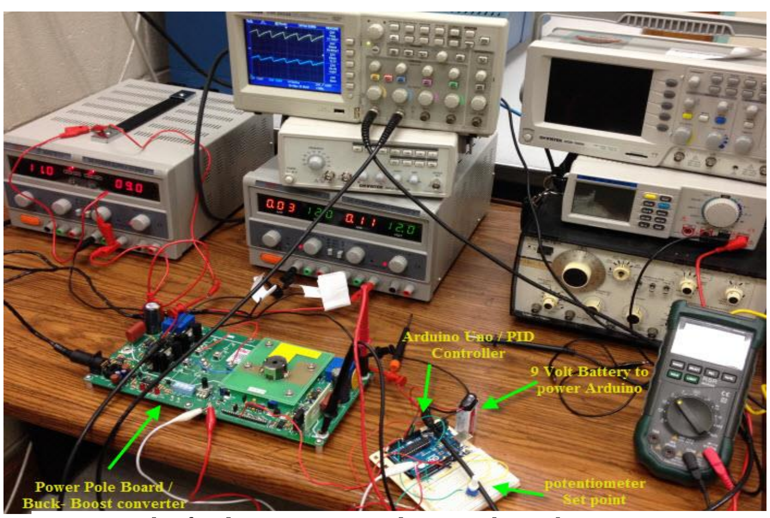



Figure 5: The final connection Arduino with Buck-Boost converter

## Discussion and results

The frequency of Arduino itself is increased to reach 15 KHz. Figure 6 shows the increased frequency of PWM that generated from Arduino pin 9. Increasing the frequency of Arduino might not occur with download models from Simulink into Arduino microcontroller directly [9]. This is also a reason Arduino code is written instead of making direct interface with Simulink.

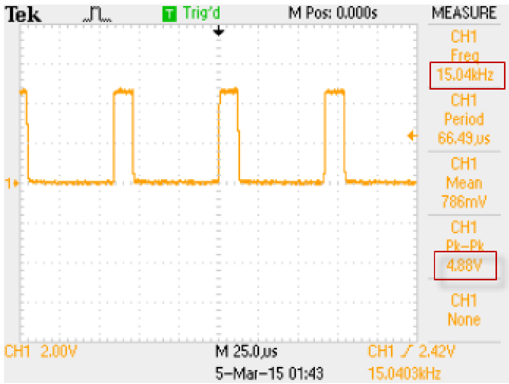
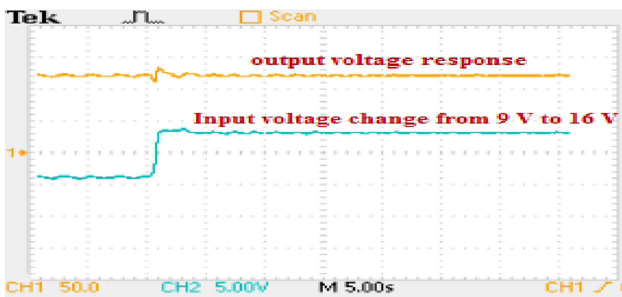
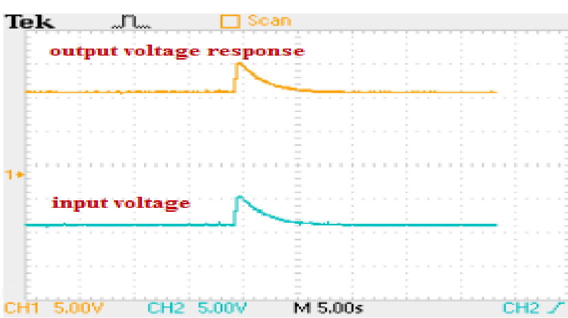



Figure 6: Arduino output PWM

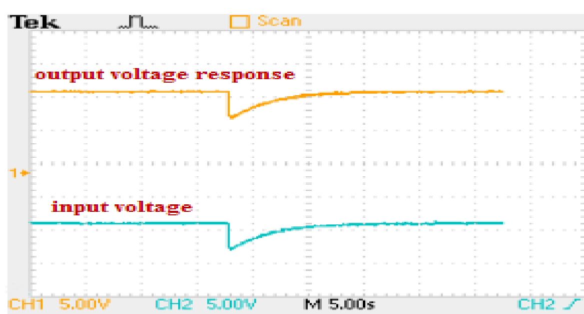
To prove the simulation results of hardware prototype for the Buck-Boost converter with the Arduino Uno, the results in the Figure **7** have been collected.




(a)




(b)




(c)

Figure 7: Results of closed loop output voltage

a: Output voltage response to input voltage changes from 9 to 16
b: Output voltage response to load changes from 40 to 70 Ω
c: Output voltage response to load changes from 70 to 40 Ω

Practically, digital PID controller has been tested in a lab. As shown in the Figure 7 (a) input voltage has changed from 9 to 16 volts, and it works correctly. However, there is still overshooting because the switching of voltage from 9 to 16 volts is performed manually from the knob of dc power supply, and the time of switching is about 3 sec. Furthermore, Table 4 from the paper of Javaid, et al.[10], shows the out voltage changes versus day of the time. The data collected on 23rd of July 2011 explained that a big change in voltage, blue highlighted, was 0.6 volt during 15 minutes. On other hands, our PID controller has been tested with voltage changes from 9 to 16 volts for about 3 second only. Consequently, the PID controller should work quite fine with photovoltaic systems.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Output Voltage | 16.9 | 17.1 | 17.3 | 17.5 | 17.5 | 17.4 | 17.3 | 17.3 | 17.2 | 17.3 | 17 | 16.7 | 16.9 | 17.4 | 16.8 |
| Time of Day | 10:15 AM | 10:30 AM | 10:45 AM | 11:00 AM | 11:15 AM | 11:30 AM | 11:45 AM | 12:00 PM | 12:15 PM | 12:30 PM | 12:45 PM | 1:00 PM | 1:15 PM | 1:30 PM | 1:45 PM |

Table 4: output voltage versus day of the time

Similarly, Figure 7 (b) and (c) shows the output voltage response to the varying in load where that load has been altered from 40 to 70 ohms and vice versa. The controller takes about 7 seconds to force the converter to come back again to steady state reference point which is 12V. Therefore, this PID controller works properly either charging a 12 volt battery or connecting straight to the load about 70Ω.

## Conclusion

To apply the PWM control technique, Arduino is used to avoid the need for complex hardware circuits. The Arduino Uno can operate as a digital PID controller to regulate the output voltage of the Buck-Boost converter that could feed by a solar panel to get constant 12V or any desired voltage. The PID controller works properly whether input voltage fluctuates or there is a change in load. The non-oscillating output voltage can be used to charge 12V DC rechargeable battery or feed a load directly. The controller is simulated in MATLAB-Simulink, and the results are compared. Also, the hardware circuit is checked practically in a lab, and it operates correctly.

## References

1 Petrone, G., Spagnuolo, G., Teodorescu, R., Veerachary, M., & Vitelli, M. (2008). Reliability Issues in Photovoltaic Power Processing Systems. IEEE Transactions on Industrial Electronics, 55(7), 2569–2580.

2 Abouobaida, H., & Cherkaoui, M. (2011). Robust controller for interleaved DC-DC converters and buck inverter in Grid-Connected Photovoltaic Systems, 6(1), 21–30.

3 Mohan, N., Power Electronics: A First Course. 2012, Hoboken NJ: John Wiley & Sons, Inc. 270

4 Mummadi, V. (2011). Design of robust digital PID controller for H-bridge soft-switching boost converter. IEEE Transactions on Industrial Electronics, 58(7), 2883–2897. doi:10.1109/TIE.2010.2077615

5 smail, N. F. N., Musirin, I., Baharom, R., & Johari, D. (2010). Fuzzy logic controller on DC/DC boost converter. 2010 IEEE International Conference on Power and Energy, 661–666.

6 Yousefzadeh, V., & Choudhury, S. (2008). Nonlinear digital PID controller for DC-DC converters. Conference Proceedings - IEEE Applied Power Electronics Conference and Exposition - APEC, 2, 1704–1709. doi:10.1109/APEC.2008.4522956.

7 Kambiz Arab Tehrani and Augustin Mpanda (2012). PID Control Theory, Introduction to PID Controllers Theory, Tuning and Application to Frontier Areas, Prof. Rames C. Panda (Ed.), ISBN: 978-953-307-927-1.

8 Rao, G. S., Raghu, S., & Rajasekaran, N. (2013). Design of Feedback Controller for Boost Converter Using Optimization Technique, 3(1).

9 Arduino Playground – Homepage. (n.d.). Retrieved March 3, 2015, from http://playground.arduino.cc/
10 Javaid, M. A., Khan, M. S., & Shaukat, S. F. (2011). Estimation of Solar Power Efficiency in Day Time at Different Temperatures, (April), 3–7.

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# Discovering the Role of Big Data in the Execution Performance of Software Development Projects

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## Abstract

Many factors can influence the execution performance of technology projects within corporate environments. Some of this data requires real-time data gathering and analysis during project execution. Such data is often neglected, misclassified, or otherwise misinterpreted which increases risk of delays, quality issues, and missed benefits.

Postgraduate educators who focus their research in this area can influence conventional industry practices by unveiling new scientific methods for assessing software project execution. In this paper, we analyze the impact, role, and influence of key project data on the management and governance of business software projects. We discover how to use specific data types and sources to balance the subjectivity currently used by Project Managers (PM's) routinely reporting on project execution progress. Engineering and technology curriculums can be greatly enhanced by these learnings. Organizations can demonstrate leadership within their industries if they adopt the recommendations which can help maximum risk-adjusted returns from their investments.

## Keywords

Big Data, Project Management, Governance, Software Projects, Data Gathering, KPI's.

## Introduction

Many factors can influence the ongoing management and execution of technology projects within the corporate business environment. Some of these elements are known a priori during the project planning phase. Others may require real-time data gathering and analysis during project execution. These real-time project data elements are often neglected, misclassified, or otherwise misinterpreted during the project execution phase increasing risk of delays, quality issues, and missed business outcomes. The purpose of this research is to discover and analyze the impact, role, and level of influence of various project related data on the ongoing management of technology projects. The goal is to provide a balance to the subjectivity currently used by project managers when assessing and reporting on project execution progress.

PM's managing software development projects have an increasingly tough job. Often times they get their inputs from technical leads who are much more technical than themselves. These technical leads may also be located offsite, offshore, or a separate physical location with the programmers. When conducting assessments they have to work within the limitations of their capabilities and competencies. PM's must also contend with the realities of their environment, the tools available to them, and the best practices within their industries and organizations:


## Software Project Management

The management of business software technology projects is a complex and interdependent process which requires the careful and complete consideration of multiple factors – subjective and objective factors. Cao & Hoffman (2011) state that using project schedules, in isolation, can result in projects falling.[1] Z.M Deng et al. (2001) previously suggested that weekly monitoring can help ensure work efficiencies and profitability and that a data input driven or graphical view can help in effectively monitoring project progress.[2] Knudson et al. (1998) acknowledged that while many software tools are available in the market place to help manage large projects such as Microsoft Project, these commercially available products are designed for specific applications and therefore can have limited capabilities in a broader management sense.[3] Iversen & Mathiassen, et al. (2000), through examining a case study as part of their research, saw a project that was progressing very slowly with limited success when considered from a technical viewpoint. However, from a cultural view point, they saw an initiative that was manipulated into a successful transformational experience laden with managerial practices. With the help of data-driven intervention and when data is collected and distributed on a regular basis, they were able to demonstrate the importance of complementing a technical view of measurement with the cultural or human side of metrics.[4] McAfee (2006) reminded us that, despite all efforts, over half of large-scale IT efforts do not meet the set schedules and consequently only 10% of efforts are acknowledged as getting high ROI's. Just a little less than half of the projects had returns that were low, negative, or worst yet, unknown.[5] Finally, Basili & Weiss (1984) underscore the crucial point that just because data can be collected does not necessarily imply that the data has been validated. Wrong KPI's and measurements contributed to incorrect or misguided results. Testing and validity of data is important.[6]

The select research that has been done regarding the management of business software technology projects, while detailed and informative, still skirts around the issue at hand – that is, how can we specifically assess software development progress and complement the subjective assessments which are traditionally conducted by management. Authors of the literature review conducted as part of this research project acknowledge the importance of technical measurements and KPI's. They also rightfully indicate the importance of collecting the right data and validating the data before developing conclusions. They accept that project management tools that are commercially available may be lacking in full capabilities.[4] The research also points to a call of action that is required since over half of the projects are still failing and only one tenth of the projects are actually realizing returns that management can be proud of. Yet, the research does not conclusively indicate any exact science or models that can be used to scientifically tabulate and establish trends on project status.[6]

## Big Data

Due to technology advancements and multiple data storage and access enhancements, there is plenty of "big data" that can be leveraged to assess processes and decision making. Aguwa & Monplaisir (2009) share the outcome of a survey where half of the respondents indicated that information and analytics related improvements are a top priority in their organization and more than 20% of them indicated feeling intense pressure to adopt advanced information and analytics approaches. He also states that top-performing organizations use data analytics five times more than lower performing organizations.[7] Rabi et al. (2012) discuss that many companies have invested in building sophisticated monitoring tools as complexity of enterprise systems increase. It is also acknowledged in the paper that big data analytics creates new challenges when it comes to systems monitoring solutions. The paper also further declares that it is now possible to capture every method invocation in a large enterprise system using APM tools but that only specific method invocations are of interest such as communication methods.[8] Marsanu (2010) highlight the importance of metrics and indicators when evaluating IT projects but that the value of the metrics depends on the quality of the data.[9] Liu & Xu (2001) introduce the concept of Product Data Management (PDM) demonstrate a use case where all information regarding product definition, process, end-to-end support and so on are brought together in an integrated fashion in one tool.[10] Finally, Tian & Zhao (2014) discuss how cloud computing techniques and solutions can solve some of the inherent problems with big data such as bottlenecks, scalability issues, installation, maintenance, fault tolerance and performance.[11]

The case for big data, the opportunities, and the issues has been made. There is no question that there is more data available today than ever before and that this data can be effectively leveraged using the right business rules and software platforms. Data analytics is a priority for many organization and many departments within an organization, including IT. Top performing processes and groups utilize big data effectively, where possible.[7] Research has been done on the applicability of big data within the context of enterprise systems management and performance. All inclusive solutions such as the PDM reviewed by Liu & Xu (2001) shows us that we can build systems that are data-based, that tell us the complete story regarding a product (or in fact even a process) and we can harvest the information for analytical purposes. Expansive storage solutions and offsite offerings such as "The Cloud" can make matters more convenient to execute. The research shows that we do have a good base and spring board for conducting meaningful work when evaluating software development in progress by using big data principles and technologies. Big data is not just for marketing. It can be used to improve processes, such as software project assessment and management.[10]

## Software Data Elements

Understanding software data elements and selecting the right elements as predictors of project performance and status is crucial. Post & Kendall (2004) advise us that any project status should be measurable. They reference work done by Jones (1998) and directly suggest measuring software capability in terms of function points which encapsulate several important complexities of software including I/O, lookups, logical partitioning, and integration points.[12] Then, Hartman & Ashrafi (2004), state that different industries may warrant different project success factors, metrics, and priorities.[13] Sathi, Morton, & Roth (1986) discuss how SLOC / SLOD ratios can be used to evaluate software size.[14] Ebert (1999) suggest that lines of code should not be taken as fixed when evaluating for real-time embedded systems but rather should be compared to historical standards and be viewed in terms of percentages. He states that a greater emphasis should be placed on integration and perhaps less on top level design.[15] Ebert (1998) computes the Return-On-Investment (ROI) of conducting code reviews and inspections and consequently shows that it saves ~6.2 hours of work later in production for each hour of reviews and inspections done up front.[16]

Many of the intuitive yet critical software data elements have been covered by the literature review which was conducted as part of this paper's research project. It is clear that lines of code, function points, and other important software attributes can be predictors of software complexity.[14] Though not covered explicitly in so many words, it is clear that software complexity drives schedule and time-to-market.[12] The literature review also suggests that ROI should be considered when suggesting additional and preemptive work efforts such as code reviews and inspections. The same rationale can be applied to the entire software development process – i.e. what are the precise data elements which can be viewed as predictors of successful software project completion. Each of these can be tabulated, prioritized, and appropriately weighted in calculating a performance index. Such an index can be subsequently be measured and reported with period-to-period trend analysis.[15] This is a key goal for this research project.

Jones (1998) and others measure the capability of software in terms of "function points" (FPs), a weighted total of inputs, outputs, inquiries, logical files and interfaces (Symons, 1988; Jones, 1998).[12] While FPs do not capture all of the complexity of scientific software, they are the best metric available in a simple form. Single lines of executable code can be converted to FPs (e.g. equation). Jones (1998) lists the equivalent single lines of code (SLOC) per FP for the common computer languages, since computer languages have different information densities:

$$\mathrm{FP} = \left(\frac{\mathrm{C{+}{+}\ SLOC}}{53} + \frac{\mathrm{C\ SLOC}}{128} + \frac{\mathrm{F77\ SLOC}}{107}\right)$$

$$\text{schedule (months)} = \mathrm{FP}^{x};\ 0.4 < x < 0.5;\ \text{use } x = 0.47$$

$$\text{real schedule} = \text{contingency} \times \text{function point schedule} + \text{delays} \tag{3}$$

$$\text{team size} = 3 + \frac{\mathrm{FP}}{150} + 0.6.$$

It is noteworthy to highlight that in 2009 the concept of Weighted Micro Function Points (WMFPs) was invented by a company by the name of Logical Solutions. This can be considered as a viable modern software sizing algorithm. This is of particular importance to the current research project at hand. WMFPs produce more accurate results than traditional software sizing methodologies while requiring less configuration and knowledge from the end user. Most of the estimation is based on automatic measurements of an existing source code. Previous methods have used SLOC to measure software size. WMFPs use a parser to understand the source code breaking it down into micro functions and derive several code complexity and volume metrics which are then dynamically interpolated into a final effort score. What is more is that WMFP are compatible with the waterfall software development life cycle methodology and newer SDLCs, such as Six Sigma, Boehm spiral, and Agile (AUP/Lean/XP/DSDM) methodologies. WMFPs offer greater precision and reduced ambiguity.

## Real-time Data Gathering

Gathering real-time data to effectively manage software which is in development is of key importance to the subject matter of this research paper. Dawson & O'Neill (2003) said that this process need not be intrusive.[17] Cauchi et al. (2013) further state that the monitoring process must be efficient and real-time.[18] Martínez-Prieto, Cuesta, Arias, & Fernández (2014) highlight a specific tool call Virtuoso that has proven to be the most effective run-time data storage offering in the context of their study.[19] Souza et al. (2012) share an approach that automatically detects conflicts, real-time, on feature specifications of the software which the authors consider important indicators of software performance.[20] Serrant-Green (2008) warns us to avoid having data collection be an overly consuming activity and being careful of not having it becoming a substitute for true problem analysis.[21] Finally, Chamberlin (2010) advises us that while most recent data may provide valuable and new information, such data is likely to encounter greater measurement error than historical data which has been given due time to settle, be analyzed, and smoothened.[22]

The literature review that addresses real-time data and data gathering is consistent with intuitive reasoning. The process must not be intrusive or consuming.[17, 21] While select tools have been reviewed in detail, flexibility of PM tools to capture real-time data is the salient point taken from this literature review. [19] Next, automation of detection and rule-based extrapolation such as conflict detection described is important to be conducted in real-time.[20] It is also equally obvious that real-time data, when newly gathered, may encounter greater measurement errors in the beginning until such time when the data is gathered on a repeatable basis.[22]

## Software Tools & Techniques

Software tools & techniques are required to effectively harness real-time, big data for effective project management. An anonymous (2010) author makes a case for Microsoft Project which allows for two-way connection of data including importing key attributes from projects and exporting valuable information that can be used to effectively manage projects.[23] Another such author (2013) makes a case for new software increasingly available in the market place which allows for an integrated system (i.e. complete system) to better manage the realities of complex projects.[24] Ali, Anbari, & Money (2008) conduct a study that demonstrate higher utilization of specialized project management software when project complexity his higher.[25] Hegde (2013) acknowledge that many commercially available PM software products are designed for specific applications and inherently offer limited capabilities.[26] Lessmann, Baesens, Mues, & Pietsch (2008) advise that learning algorithms offer a novel technique in contrast to traditional project management software and processes.[27] Finally, Rivas, Perez, Mendoza, & Griman (2010) insist that software project management must be plan-driven and quantifiable through and through each step.[28]

Effective project management software acts as a tool that can be configured to adapt learnt best practices over time and for various applications. Microsoft Project tends to be a leading software package that is configurable and offers two-way, bi-directional integration that can be very useful to effectively measure software development.[23, 24] It is intuitive that such software is increasingly used for projects that have higher complexity.[25] It is equally important to plan on investing time and resources to customize project management software to suit specific industry requirements and individual company requirements to maximize its function and most effectively manage projects.[26] It is exciting and promising for this research effort to read that learning algorithms may be a possibility to advance software metrics.[27] In any event, measurability is key and without which project planning cannot be effective.[28] In a later section of this paper, we will discuss a Microsoft Project based example which will demonstrate how the software configuration can be enhanced to track information and metrics of particular relevance to this research paper.

## Research Drivers

Software development has been underway for over 50 years. Yet performance statistics show that much improvement is needed in how we conduct and manage software projects. This is particularly important in a business context, where the realities of evaluation mechanisms almost solely focus on financial performance and ROI figures. Numerous studies show lack-luster performance year-over-year. Below we share an example of one such study:

**RESOLUTION**

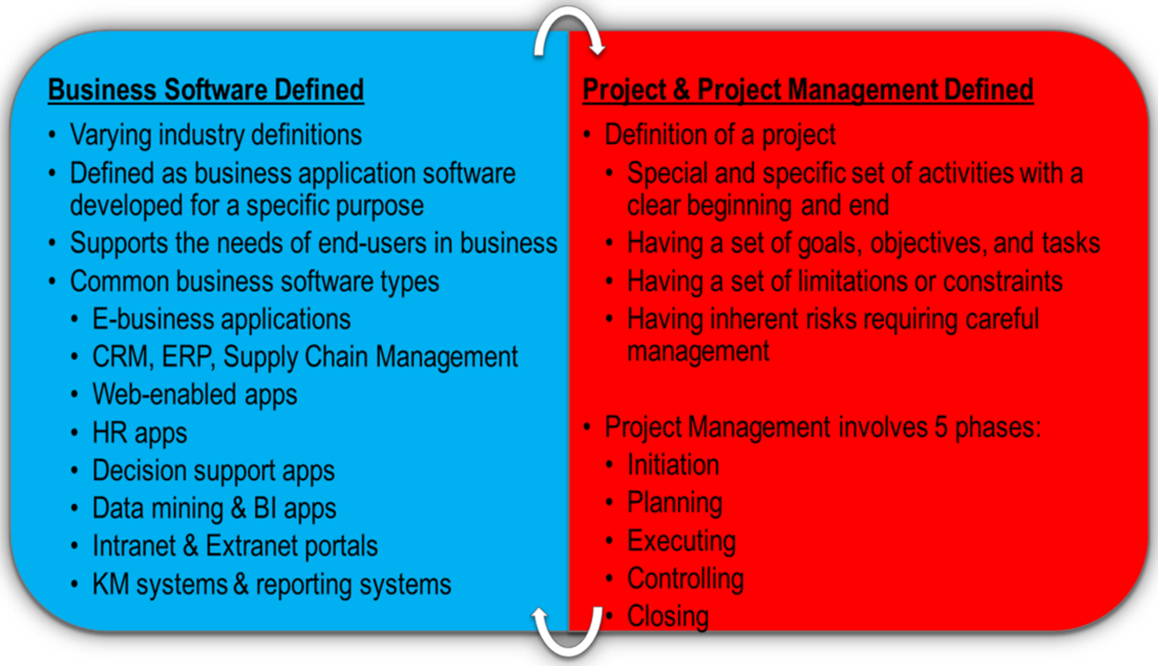
| | 2004 | 2006 | 2008 | 2010 | 2012 |
|---|---|---|---|---|---|
| **Successful** | 29% | 35% | 32% | 37% | 39% |
| **Failed** | 18% | 19% | 24% | 21% | 18% |
| **Challenged** | 53% | 46% | 44% | 42% | 43% |

Project resolution results from CHAOS research for years 2004 to 2012.

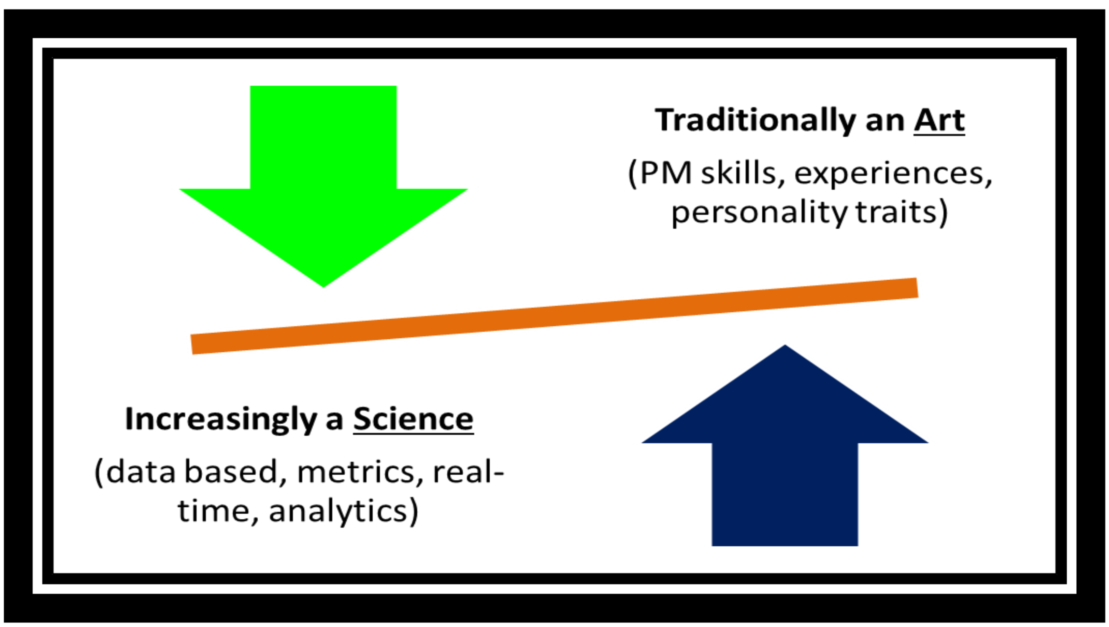
It is rather unfortunate that despite the improvements resulting from an increase in software environment sophistication, high levels of related investments being made, healthy economic growth, and improvements, business software project execution performance has still been rather flat without material improvement, year over year, and across industries.  Furthermore, most improvements cited by organizations are apparent anomalies and highly correlated to reduction of project scope, reduction of complexity, and ultimately due to lower function points and not due to improved organizational capabilities.

The low success rates resonate a loud call for action and a case for change. As we have discussed so far, several factors are in play when it comes to software technology management:


At this time it maybe also helpful if we review the current definition and state of business technology software and what is that we exactly mean by project management of such components:




Particularly in the business setting, the problem has been exasperated as project management as a discipline has morphed into an art form. Technical measurements and performance indicators are foreign speak to many technology managers working in industry today. Therefore, we submit that a quest for achieving balance must be pursued. We must appropriately re-focus our project management institutes, engineering and information systems academia faculty and students, the foundations of our PM supporting technology, and the influence senior management has on project management within their organizations:



## Scope & Research Questions

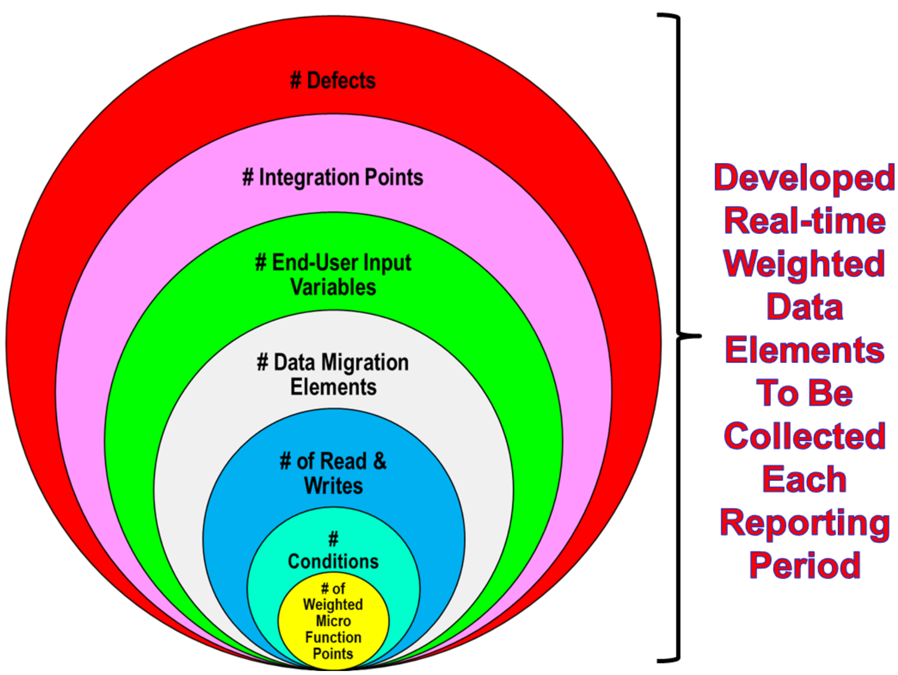
In this paper, we want to examine how the PM can be assisted in evaluating software project execution performance using greater objectivity and scientific methods. These methods can help balance PM soft competencies as well as the hard realities of the projects they are expected to manage. To narrow the scope of the project, the following specific research questions have been developed:

1. **The What:** *What are the specific project data elements that can be gathered from business software technology projects? What is the impact, role, and level of influence of these data elements on the ongoing management of such projects?*

2. **The How:** *Which tools and techniques are available to project managers and how can they best be used to harvest the identified real-time project data elements (i.e. data collection, analysis, and utilization) during the main phases of a project life-cycle (i.e. Initiation, Execution, and Transition & Value Capture)?*

## Making the Case for Big-Data – The Hypothesis

There are volumes of rich real-time data available from business software when it is under development. This data can be harvested to provide a scientific assessment of current project status to complement traditional and subjective reviews. Based on the research, we submit that the following seven (7) key software data elements to be considered to evaluate software development efforts. In effect, these are the Key Performance Indicators (KPIs) we can use to measure software project performance:



Since there are numerous definitions and even more interpretations of these software data elements, a baseline of definitions is required for a scientific model to be valid. In addition, we must recognize that the relative priority of each data element may be different. Definitions, applied weights, and denotations are being presented for review below:

| Select Software Data Element | Defined As | Timing | Applied Weight | Denoted As |
|---|---|---|---|---|
| Number (#) of Defects | Numerical quantification of the number of defects experienced (e.g. software not performing to explicit or implicit, known or anticipated requirements) for the application software to be measured. | Every Reporting Period | 10 % | wD |
| Number (#) of Integration Points | Numerical quantification of integration systems external to the application software component to be measured. | Every Reporting Period | 10 % | wIP |
| Number (#) End-User Input Variables | Numerical quantification of inputs expected from the end-user of the application software component to be measured. | Every Reporting Period | 10 % | wEUIV |
| Number (#) of Data Migration Elements | Numerical quantification of the number of data fields or constructs being migrated for the successful performance of application software component to be measured. | Every Reporting Period | 10 % | wDME |

| | | | | |
|---|---|---|---|---|
| Number (#) of Read & Writes | Numerical quantification of number of external-storage based input and outputs (i.e. databases and files) | Every Reporting Period | 15 % | wRW |
| Number (#) of Conditions | Numerical quantification of the number of conditional logic functions (e.g. if-then-else) incorporated within the application software component to be measured. | Every Reporting Period | 15 % | wConditions |
| Number (#) of Weighted Micro-Function Points | Numerical quantification of the number of WMFPs addressed by the application software component to be measured. | Every Reporting Period | 30 % | wWMFP |

### The Business Software Performance Index

Based on the build-up from the research conducted thus far, in this section we introduce the Business Software Performance Index (BSPI). The BSPI is based on the seven key weighted software data elements discussed earlier in this paper. Next, it must be acknowledged that most business software systems are in fact complex sets of systems spanning over one or more software components. Today's business environment and software requirements are indicative of the hard reality that seldom can a viable business application be deemed designed with only a single component or even a mere few. Therefore, the BSPI needs to accommodate the complexity by taking into consideration the key software data elements across all components. The simplest way to accomplish this is to average the numbers across all the components. We then derive an indicator of software performance which can be tracked and trended across multiple reporting periods:

$$\text{BSPI} = \frac{\sum_{1}^{\substack{n=No.of\,Software\\ Components}} \begin{pmatrix} wWMFP+ \\ wConditions+ \\ wRW+ \\ wDME+ \\ wEUIV+ \\ wIP+ \\ wD \end{pmatrix}}{n}$$

The tabulation and tracking of the BSPI is at the heart of this paper's recommendations. Such a model can give organizations the ability to programmatically, and without variations caused by interpretations, measure relative performance of their software projects. The BSPI is measured and is relative across two dimensions: (a) by reporting period and (b) compared to historical data from other projects completed within the subscribing organization.

**The Intrinsic Value of Historical Data**

Confucius reminded us to "study the past as if it would define the future." This has been conventional wisdom and generally a widely accepted practice. Within the context of big data within the business context and data analytics, the science of predictive modeling has been suggested in recent times. Yet a few innovative thinkers such Beaulieu & Love (2011) strongly submit that we should forget the past and doing so can be the key to the future.[29] Such forward thinkers go on further to claim that being stuck in the past in fact dismisses future innovation and that considering historical norms does not take in to account the changing environment, dynamics, capabilities, future drive, and so on.[29] Given this type of thinking and in the context of measuring software performance from project to project as well as the use of the BSPI for subscribing IT organizations to gauge status of a given software development project, the following must be acknowledged and otherwise assumed to be the case:

1. *Maintain Status-Quo Process* – Subscribing organization in fact seldom change materially with respect to their capabilities and resources after one project to the next project. Any change in process can be specifically factored into the subsequent tabulations of the BSPI for their projects.

2. *Availability of Resources & Performance Data* – Subscribing organizations have the capability and resources to build a historical database from past projects with respect to the seven key software elements and consequently the BSPI for each project.

3. *Availability of Project Profile Data* – Subscribing organizations have benefit realization information for past software projects – e.g. performance against plan (budget, time, quality business benefit, etc.)

The greater the quality of historical data, the greater the ability to predict the future. With the above key assumptions and creating the in-house ability to calculate the BSPI, organizations can systematically track software development performance and, in essence, “double validate” the qualitative assessments developed and shared by PM’s.

**Measurements**

This research aims to make a conceptual case for increasing the scientific and objective techniques that can be adopted to measure software development performance and consequently assess a realistic, data supported, status of a project. Methods for measuring and harvesting past, current, and future BSPI data can vary and be personalized by subscribing organizations. Much will depend on the availability of human and systems resources, the level of sophistication of IT within organizations, and their seriousness and commitment to the cause at hand.

The code snippet below is an illustrative example of how a conventional and simplistic method can be used to tabulate key software data elements required to calculate the BSPI. It is fully expected that subscribing organizations, with their muscle and access to valuable resources, can accomplish the same using greater sophistication and automation:

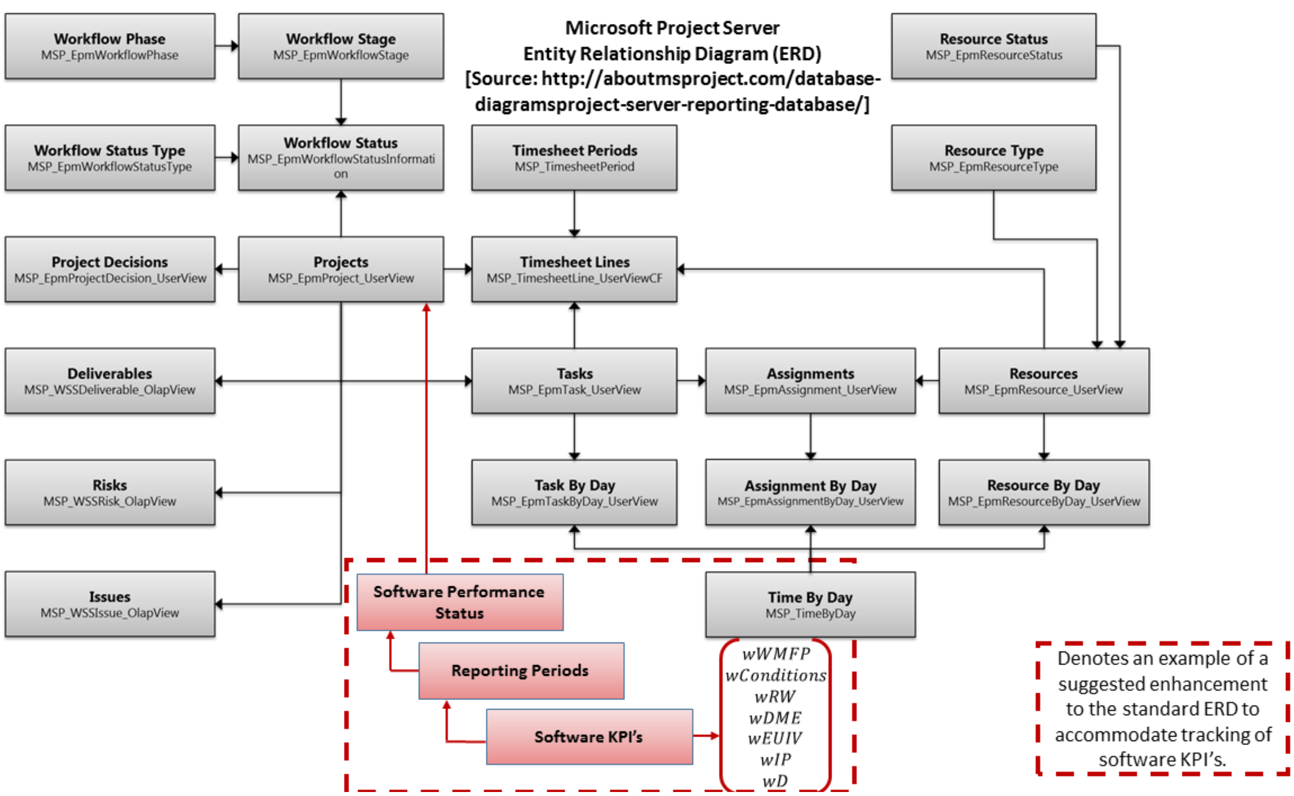
```
#/////////Sample Python and MySQL code (shaded) added to a conventional
#program to tabulate conditional statement that can be later
#used for calculating the BSPI////////////////////////////////


import MySQLdb

db= MySQLdb.connect(host="localhost", user="python-test", passwd="python",
db="python-test")
try:
    iPadinput1 = raw_input("Please enter a book title: ")
    if iPadinput == "" :

        cursor = db.cursor()

        stmt = "INSERT INTO BspiMetricsDB (Component, SoftwareMetricType, Count)
VALUES ('"
        stmt = stmt + “’Sample Program To Track Performance”
        stmt = stmt + "', '"
        stmt = stmt + “’IF Conditional Statement’”
        stmt = stmt + "', "
        stmt = stmt + “’1’”
        stmt = stmt + ")"
        cursor.execute(stmt)

        cursor.close ()
        db.commit ()

        exit

    iPadinput2 = raw_input("Please enter the author's name: ")
    iPadinput3 = int( raw_input("Enter the publication year: ") )
except:
    print "Invalid value"
    exit
```

```
print "Title: [" + iPadinput3 + "]"
print "Author: ["+ iPadinput2 + "]"
print "Publication Date: " + str(iPadinput3)

cursor = db.cursor()

stmt = "INSERT INTO Books (BookName, BookAuthor, PublicationDate) VALUES ('"
stmt = stmt + title
stmt = stmt + "', '"
stmt = stmt + author
stmt = stmt + "', "
stmt = stmt + str(pubdate)
stmt = stmt + ")"
cursor.execute(stmt)
print "Record added!"

cursor.close ()
db.commit ()
```

## Enhancing Conventional Tools & Techniques

The BSPI can be a useful mechanism for evaluating software development progress in addition to other methods, including qualitative assessments conducted by PMs. Most organizations prefer to increase efficiency, over the use of manual methods, by deploying a single or a set of project management tools. Further to that, and based on experience and PMI standards, larger organizations tend to develop and adopt their own Software Development Life Cycle (SDLC) frameworks and related processes. These methods often have guidelines, either implicit or explicit, supplied to their PMs. Unfortunately, achieving consistency in the application of the tools and methods within and across organization is a constant challenge even today. Fortunately, the tracking of BSPI and its related data components can be conducted systematically by use of enhanced PM tools which are already widely adopted by industry. The following are popular tools that can be enhanced, either by the vendors through the product offering itself, or by custom configuration and extensions. These extensions can be developed by subscribing organizations, free-lancers, or open-source groups who are familiar with these tools and also utilize them through every day application:


In the reminder of this section of the paper, we will cover an example of how this can achieved using Microsoft Office. The logical data model of Microsoft Office is represented best by the data model for Microsoft Project Server. This off-the-shelf software product is industry leading and inherently capable to store and track the pertinent project management data. A simple extension of the data model can be made to track the required elements for software project status:




The above ERD and suggested enhancement shows that the standard data model can be extended to track and report on the necessary software KPIs discussed in this paper. Once this is accomplished, the PM reports and analysis can be conducted by experienced PMs for each software project that is underway within their span of control.

Vendors such as Microsoft, Google, and others can be persuaded by the larger subscribing organizations to include such functionality in their project planning and related software products. The business value is intrinsic by the suggested enhancements such as the modified ERD reviewed in this section. Even still, if vendors cannot be persuaded, subscribing organizations can extend the project planning and tracking functionality by customizing other data gathering and analytical tools that may be available at their disposal. Data can then be migrated and merged from products such as Microsoft Project to create a consolidated view. Doing so can still achieve the anticipated benefits of the BSPI. The only difference will be that it will be a two-step process rather than a single integrated process.

## Conclusion & Recommendations

Big data from software can indeed be used to assess project status with greater objectivity. While a lot of data is available or can be derived, the BSPI scientifically measures project status for each reporting period. Organizations will benefit greatly from harvesting BSPI related data, comparing it to historical levels, and contrasting and augmenting it to conventional and qualitative project assessments. To do so, subscribing organizations must accomplish five (5) key steps:

1. *Ensure Readiness* – Conduct thorough change management to convince the key stakeholders of the intrinsic value of measuring software performance systematically and including it as a critical part of project management related KPIs for software projects. Management must believe in their KPIs for this to work.

2. *Validate Applicability* – Validate the components and weightings of the BSPI for applicability to their organizations and projects.  Management must make this personal and specific to their organization, business, and industry.

3. *Enable Adoption* – Modify their SDLC frameworks to include the BSPI and related software data elements. Management must help their staff adoption new ways of measuring and modify the way they conduct projects.

4. *Provide Support* – Enhance the necessary PM software, tools, techniques, and guidelines to facilitate the new tracking capabilities. Management must support the efforts of their staff by providing the necessary tools and resources to be successful.

5. *Plan for Sustainability* – Ensure careful inspection of results, action orientation based on metrics, and training of key personnel responsible for adoption. Management must care about the results, inspect outcomes, and support the execution of related actions plans.

In the end, organizations always change with their experiences from past challenges and successes.  Management must consider organization learning and betterment a priority and must examine every metric it sanctions for collection and measurement.  There is a lot of data available. But much of has been proven to be noise if not collected and organized properly as well as inspected correctly.

It was W. Edwards Deming, the famous American statistician and author, who was credited for saying "you can expect what you inspect." While dated over one-hundred years ago in history, this quote is an appropriate message to share as we conclude this research paper. We put forth the responsibility of educating students on the concepts presented in this paper in the hands of our esteemed educators. They have the sole power to influence long term and lasting behavior. Educators can do so by judiciously focusing their classroom time on the key concepts offering students a chance to learn, engage, develop and extend the research and most importantly make a difference in the future of software project management.

## Future Opportunities for Research & Application

Tremendous opportunity remains ahead for academia, subscribing organizations, and standards related or educational associations (e.g. PMI, ASEE, others) who can further the research or increase the adaptation of the ideas developed and presented by this paper. To be specific, a select few such opportunities for the future have been presented below:

- Develop data collection code-parsers for all popular coding environments (e.g. Java, Pearl, C, Visual Basic Script).
- Develop workflows to automate the BSPI calculations and trending across multiple platforms.
- Test the hypothesis against several projects from industry with permission and required non-disclosures.
- Collaborate with software providers to enhance industry leading and configurable PM tools to collect and analyze the seven (7) key data elements – i.e. the big data from software.
- Develop change management plans that subscribing organizations can adapt to more scientifically measure software project performance using the BSPI.
- Seek endorsements and support from credible organizations that can help advance the research topic and adoption.
- Simulate with data from multiple projects with multiple replications and what-if scenario analysis using different weightings that the ones suggested in this paper. It is possible that more optimal scenarios than those presented in this paper are discovered by conducting a simulation exercise.

## References


1. Cao, Q. and J.J. Hoffman, *A case study approach for developing a project performance evaluation system.* International Journal of Project Management, 2011. **29**(2): p. 155-164.
2. Deng, Z., et al., *An application of the Internet-based project management system.* Automation in construction, 2001. **10**(2): p. 239-246.

3. Knudson, J.G., W.L. Vivian, and M.S. Crego, *Dynamic project management system*, 1998, Google Patents.
4. Iversen, J. and L. Mathiassen. *Lessons from implementing a software metrics program*. in *System Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conference on*. 2000. IEEE.
5. McAfee, A., *Mastering the Three Worlds of Information Technology.* Harvard Business Review, 2006: p. 1-10.
6. Basili, V.R. and D.M. Weiss, *A methodology for collecting valid software engineering data.* Software Engineering, IEEE Transactions on, 1984(6): p. 728-738.
7. Aguwa, C. and L. Monplaisir. *Collaborative architecture framework for the design & manufacturing of medical devices*. in *Management of Engineering & Technology, 2009. PICMET 2009. Portland International Conference on*. 2009.
8. Rabl, T., et al., *Solving big data challenges for enterprise application performance management.* Proceedings of the VLDB Endowment, 2012. **5**(12): p. 1724-1735.
9. MARSANU, R., *Project Management Metrics.* Oeconomics of Knowledge, 2010. **2**(2): p. 10-15.
10. Liu, D.T. and X.W. Xu, *A review of web-based product data management systems.* Computers in industry, 2001. **44**(3): p. 251-262.
11. Tian, W.D. and Y.D. Zhao, *Optimized Cloud Resource Management and Scheduling: Theories and Practices*2014: Morgan Kaufmann.
12. Post, D.E. and R.P. Kendall, *Software project management and quality engineering practices for complex, coupled multiphysics, massively parallel computational simulations: Lessons learned from ASCI.* International Journal of High Performance Computing Applications, 2004. **18**(4): p. 399-416.
13. Hartman, F. and R. Ashrafi, *Development of the SMART TM project planning framework.* International Journal of Project Management, 2004. **22**(6): p. 499-510.
14. Sathi, A., T.E. Morton, and S.F. Roth, *Callisto: An intelligent project management system.* AI magazine, 1986. **7**(5): p. 34.
15. Ebert, C., *Technical controlling in software development.* International Journal of Project Management, 1999. **17**(1): p. 17-28.
16. Ebert, C., *The quest for technical controlling.* Software Process: Improvement and Practice, 1998. **4**(1): p. 21-31.
17. Dawson, R. and B. O'Neill, *Simple metrics for improving software process performance and capability: a case study.* Software Quality Journal, 2003. **11**(3): p. 243-258.
18. Cauchi, A., et al. *Using Medical Device Logs for Improving Medical Device Design*. in *Healthcare Informatics (ICHI), 2013 IEEE International Conference on*. 2013.
19. Martínez-Prieto, M.A., et al., *The Solid architecture for real-time management of big semantic data.* Future Generation Computer Systems, 2014.
20. Souza, I.S., et al., *Evidence of software inspection on feature specification for software product lines.* Journal of Systems and Software, 2013. **86**(5): p. 1172-1190.
21. Serrant-Green, L., *Data gathering.* Nurse Researcher, 2008. **15**(4): p. 4-6.
22. Chamberlin, G., *Real time data.* Economic & Labour Market Review, 2010. **4**(6): p. 68-73.
23. Anonymous, *Selerant Product Lifecycle Management Solution Integrates with Microsoft Project.* Entertainment Close - Up, 2010.

24. Anonymous, *PROJECT MANAGEMENT SOFTWARE.* Rock Products, 2013. **116**(4): p. 38.
25. Ali, A.S.B., F.T. Anbari, and W.H. Money, *Impact of organizational and project factors on acceptance and usage of project management software and perceived project success.* Project Management Journal, 2008. **39**(2): p. 5-33.
26. Hegde, V. *Role of human factors / usability engineering in medical device design*. in *Reliability and Maintainability Symposium (RAMS), 2013 Proceedings - Annual*. 2013.
27. Lessmann, S., et al., *Benchmarking Classification Models for Software Defect Prediction: A Proposed Framework and Novel Findings.* Software Engineering, IEEE Transactions on, 2008. **34**(4): p. 485-496.
28. Rivas, L., et al. *Selection model for software project management tools in smes*. in *Software Technology and Engineering (ICSTE), 2010 2nd International Conference on*. 2010. IEEE.
29. Beaulieu, R. and K.G. Love, *Forgetting the past: The key to predicting the future.* International Journal of Humanities and Social Science, 2011. **1**(9): p. 1-15.

# Emulating the Functionality of Rodents' Neurobiological Navigation and Spatial Cognition Cells in a Mobile Robot

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## Abstract

A unique roving robot navigational system is presented here, which is inspired by rats' navigational and spatial awareness brain cells. Rodents, as well as all mammalians, are capable of exploring their surroundings when foraging or avoiding predators, and remembering their way home or to the closest known shelter through path integration. This is true for other creatures, but the neural cells involved in accomplishing these tasks have been most notably studied in rats, as they share certain similarities with a human's brain. The robot built in this study, named *ratbot*, uses characteristics and interpreted functionalities of the specialized navigational and spatial cognition brain cells, which are primarily found in the hippocampus and entorhinal cortex. These cells are the: place cells, head direction cells, boundary cells, and grid cells, as well as memory used for the storage and access of salient distal cues. Similar to a rat, the *ratbot* uses path integration to navigate from one waypoint to another. This is accomplished through use of vectors and vector mathematics. Additionally, the *ratbot* uses a field programmable gate array to emulate grid cell inspired functionality for environment mapping and spatial cognition.

## Keywords

Neuron, Spatial Cognition, Proprioceptive Stimuli, Vestibular Stimuli, Salient Distal Cues.

## INTRODUCTION

Many mobile robotic navigation and mapping systems have been studied and developed over the past several decades. Continued technology advancements gained by Moore's Law (e.g., shrinking of computing packaging) have helped fuel this area, as well as advancements in robotics in general. As with any system design, these robotic navigation and mapping systems are designed to achieve the goals of its application, while optimizing on given constraints. Such constraints include: goals, performance measurements, cost, size, power consumption, computing resources available, etc. For example, an autonomous mobile robot which uses a complex navigation system, and requires high accuracy over many different environmental conditions, is the self-driving car. Such a system requires many expensive sensors and computational resources (for obvious safety reasons), such as: LIDAR, RADAR, GPS and video cameras, as well as complicated, compute intensive multi-sensor fusion, information fusion and visual processing algorithms [1-5].

As illustrated by this example, it is very difficult to emulate in a machine that which comes naturally and instinctively to humans, animals, insects, etc. Given tight constraints, such as limited platform size (17.5 cm x 21.5 cm for the *ratbot*), it becomes that much more difficult to emulate a neurobiological based navigation system which possesses much accuracy. However, that is the precise goal of the system design presented in this paper, and its implementation in the *ratbot*.

Therefore, this paper brings together a culmination of animal and insect navigation related observations and laboratory findings from researchers in the fields of neuroscience, biology, and zoology. In particular, the focus of the collected research material falls into the following two areas: (1) observations made of insects, mammals, and other animals in their travel patterns, along with the conjecture that their brains are continuously performing vector summations to calculate a straight vector "home" [6-8], also known as path integration (PI), and (2) the study of specific brain cells in rats found to be involved in navigation and spatial cognition [6, 9-19].

## A. Vectors for Path Integration

Path integration was first suggested by Charles Darwin [20], and further experimental evidence of this hypothesis was shown in [21]. Figure 1 illustrates the concept of PI used by animals, as well as the *ratbot*. In this figure, the rat leaves its home, travels around the enclosed area until it finds food, then returns directly home. As previously described, such a foraging task is accomplished by the rat continuously updating a cognitive return vector to its home based on changes in its head direction, via vestibular stimuli, and distance traveled, via proprioceptive stimuli.

Initially, PI is dependent on both external and internal stimuli. However, once a path or area has been learned, the need for external stimuli has been shown not to be required in rats [6, 15, 22], as well as other animals and insects, to successfully navigate around a known area. Despite this ability, relying on internal stimuli alone, causes for an accumulation of calculated location error. If possible, this growing error should be reset to zero by occasionally adding external stimuli (e.g., visual, smell, tactile, etc.) to reveal a salient distal cue. Without periodic affirmation of current position, this error will grow without bound [23].

The relationship between the navigational specific brain cells found in rats and PI (e.g., waypoints, vectors out and return), as is discussed in [6, 7, 24], will be covered in the neuroscience background section.

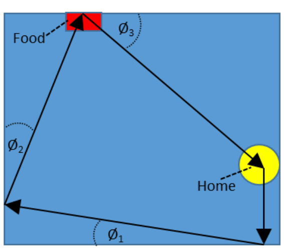


**Figure 1.** Path integration example.

**a)** **b)**

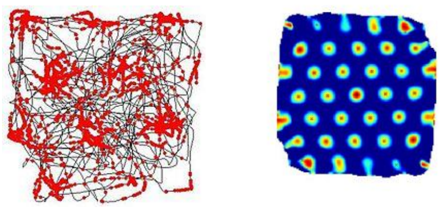

**Figure 2. a)** Recorded firing locations (red dots) of a single grid cell, as a rat explores (black line) a square, enclosed area. Such recordings are obtained by installing an electrode in a rat's cerebral cortex (dorsomedial entorhinal cortex or dMEC), where it picks up the firing of a single grid cell as the rat moves around his enclosure. The rat's actual location is recorded with a camera or similar and matched up with the grid cell's firing data. **b)** The autocorrelogram of the firing data for the grid cell. Each firing region for the single grid cell in a can be statistically auto correlated, resulting in a spatial autocorrelogram of the same neuron's firing activity. The hexagonal pattern of the firing locations can be seen in both parts **a** and **b** of the figure.

The study and presentation of PI usually focuses on the measured movements and calculations leading up to the home bound vector or waypoint vector. However, an equally important area of study is how the brain deals with navigating around both known and unknown barriers, which intersect the single return vector. For example, Figure 3a illustrates a minor barrier in the home bound vector path, while Figure 3b illustrates a more complex barrier in the path. Each barrier should pose no problem for a rat that has previously traversed the area, whether there is external stimuli or not. However, if the rat (or mobile robot) has no prior knowledge of either barrier, and has low- to no- external stimuli, then the scenario in Figure 3b becomes much more complex for traversing. These examples illustrate the need for a mapping/recall capability, so that the rat or mobile robot is able to optimally traverse the landscape. This is where spatial cognition capabilities become of great importance and is uniquely addressed in this paper.

**a)** **b)**

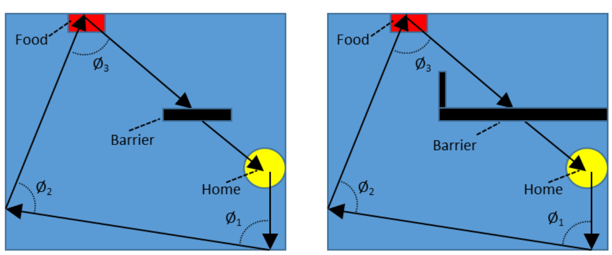


**Figure 3. a & b)** Examples of a known or unknown barrier in the home bound vector path.

As for the *ratbot*, PI is implemented through the use of a central microcontroller (Arduino microcontroller board) for calculating vectors, motor encoders for distance traveled information, and a microelectromechanical systems (MEMS) based gyroscope for measuring change in head direction. Since the *ratbot's* vision is implemented with a forward looking ultrasonic sensor, the visual data obtained is in the form of the distance to an object directly in front of the *ratbot*. Therefore, the *ratbot's* vision can be used for object/barrier detection and avoidance purposes only, and must rely heavily on the internal stimuli of the system. This creates a growing localization error/uncertainty problem [5, 25, 26]. However, if the location of barriers and obstacles can be statistically identified with the internal stimuli data, then it can be mapped into the spatial cognition memory for possible use in path planning (Figures 3a & 3b).

## B. Spatial Cognition in Robot Navigation

Through the use of a field programmable gate array (FPGA), the *ratbot's* environment is logically mapped into a two dimensional array of parallel processing units. Each unit is an instantiated grid cell's firing location/region, similar to that shown in Figure 2b. In a rodent or any mammal, a single grid cell fires whenever the animal has crossed (or stopped on) a spot that the animal has visited before. The reason the author uses the word region is due to the fact the physical location is not actually a single spot, but rather a statistical region around a spot, as illustrated in Figures 2a & 2b. However, to the animal's brain, it is the same spot, thus illustrating error in external and internal stimuli based measurements. Despite the accumulated errors, the regions of all of the firing locations of a single grid cell tend to be of similar shape and size. Also, the firing regions make a hexagonal lattice shape, which is constructed of equilateral triangles. Each vertex of the equilateral triangle is a particular firing node or region. The hexagonal lattice firing locations of a single grid cell covers the entire local environment that the rat is currently exploring. The firing characteristics of a grid cell, as well as more detail on all of the specialized navigation cells of a rat's brain, are covered next. Additionally, a greater detailed discussion of the FPGA's use is covered in the implementation section.

# NEUROSCIENCE BACKGROUND

Since the discovery of place cells in a rat's hippocampus by O'Keefe and Dostrovsky in 1971 [11, 12], research has continued to increase in this area over time, particularly as other specialized, navigation and cognitive mapping cells have been discovered along the way. These cells include: place cells, head direction cells, boundary cells, and most recently discovered, grid cells. A brief description of the characteristics of these navigation and spatial cognition cells follow.

## A. Place Cells

Place cells are a type of neuron that fires when a rat is in a particular region of a larger, containment area. The place cell will not fire until the rat has "learned" a particular location by traversing it first. Thus, several of these place cells, each with their own firing region within the rat's containment area, will map the areas that the rat has previously discovered. One might ask, how do the place cells differentiate between regions in an environment, particularly if the enclosure is a perfect square with no salient distal cues. The answer may lie in the fact that not all external cues are being eliminated. For example, a person placing snacks in pseudo random spots in the environment while the rat is foraging, may be picked up by the rat's vision. It is also possible the rat picks up on breezes, smells, etc., although these artifacts are typically "eliminated" from the test environment to the best of the testers' knowledge and abilities.

Place cells will continue to fire at their preferred location, once learned, even when the rat is unable to see. How this is accomplished is not known at this time.

## B. Head Direction Cells

In addition to place cells, head direction (HD) cells/neurons were discovered in rats some 12 years after place cells [18, 19]. Although HD cells were identified in the post-subiculum, which is part of the hippocampal formation [18, 22], they are also present in other areas of the brain as well. Each place cell has its own preferred direction of the rat's head in the horizontal plane, regardless of the rat's location, eye movement, and the angle of its head with respect to its body [22, 27]. In addition, the collective set of preferred directions of the HD cells will typically fall into a finite, correlated set. For example, one will find some HD cells that have maximum firing when the rat's head is pointed north, some when it is pointed northwest, and the rest when the rat's head is pointed southeast (these are just example directions and relativity). Once a rat is entered into an environment, these HD cells seem to align relative to a dominant, external cue. If the rat is taken out of the environment and the external cue is moved, or the environment is rotated, the preferred directions will rotate with respect to the new cue position by the same relative amount. Thus, eliminating the possibility that the earth's magnetic poles having an influence on HD.

**a)** **b)**

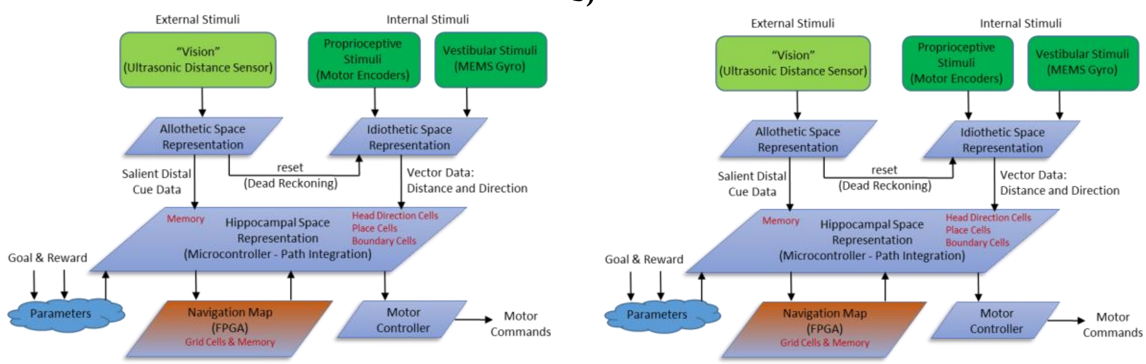


**Figure 4.** **a)** Mapping of a rat's conceptual navigation and spatial cognition system to **b)** the ratbot's system (adapted from [22]).

HD cells are similar to place cells, with respect to the fact that they will continue to fire at their preferred head direction, once learned, in the absence of external stimuli. Although, after time, these internal compasses will start to drift.

## C. Border Cells

Border cells are similar to place cells, such that a single border cell will only fire at a particular area or region of the rat's environment [9, 10]. However, border cells, as the name implies, only fire along the borders of the rat's environment. The border cell does have some unique properties over the place cell, however, the *ratbot's* navigational system doesn't need to distinguish between border cells and place cells. Thus, border cells won't be used for our navigation system per se, but may fit into future needs.

## D. Grid Cells

Grid cells are the last spatial cognition neurons discovered to date in a rat's brain. They were discovered by Edvard and May-Britt Moser in 2005 [6, 15-17]. This discovery, as well as John O'Keefe's discovery of the place cell back in 1971, earned O'Keefe and the Moser's the 2014 Nobel Prize in Physiology or Medicine. The grid cell is very unique as compared to the other spatial awareness and navigational cells covered thus far. As discussed previously and illustrated in Figure 2, a single grid cell doesn't fire in just one learned region of a rat's environment, it fires in many small regions of the environment. What makes the grid cell even more interesting is that as the rat learns his or hers environment by traveling over it again and again, a single grid cell will fire in a perfect pattern of hexagonal/equilateral triangles, at their vertices, that geometrically map over the rat's local environment.

Figure 2a and 2b illustrate a single grid cell's activity as a rat explores its area. However, there are actually many grid cells active at any given time. Additionally, differences from grid cell to grid cell occurs in three ways: (1) spacing, i.e., distance between firing regions, (2) orientation, i.e., firing location changes relative to rotation about a given axis, and (3) phase, which is a relative displacement of the firing regions [6, 15, 16]. Rather than going into greater detail of these difference, it should be noted that the combined firing regions of all these grid cell should cover every part of the rat's local environment or at least a significant part of it. How all of the activity of these grid cells work together for navigational and spatial awareness is not truly known at this point. This is also true of the other specialized cells just covered in this section.

### E. The Human Brain's "GPS"

It is believed that humans have the same navigation and spatial cognition cells in our brains as do rodents [28]. However, these cells are speculated for being used not just for learning our surroundings for navigation and mapping, but for episodic memory storage and recall as well [29].

### F. Putting It All Together

As briefly stated before, the neural circuitry of these cells are unknown. However, it can be assumed that their functionality and connectivity are somehow related. This topic in itself could be, and has been, split into several sub-studies and papers. What is known is that the external cues via visual or whisker sensory, proprioceptive stimuli in the form of motor/muscular feedback, and vestibular stimuli in the form of inner ear type feedback, are the major influences in stimulating and integrating these specialized cell systems, as illustrated in Figure 4a.

The following example is the author's interpretation of the overall role that the navigational and spatial cognition brain cells behave when a person is learning a new environment. Correspondingly, this ideology is carried over into the *ratbot's* navigational system: When one stops to think how a person remembers where they parked their car at a mall or grocery store that they have never visited, typically one takes note of salient distal cues near the car that won't likely change (using the red sports car next to you as an external cue won't help much if it is gone when you come back from shopping!). These cues may include alignment with large nearby structures, such as: light posts, trees, building fronts, grass islands, embankments, etc. At this point, one or more place cells will begin to fire at this location due to the learned alignment to external cues. Additionally, the head direction cells will become aligned relative to some relation of these external cues at the "home" place cell. As one walks towards the store entrance, the relative distance walked adds more information for the firing of grid cells. Other non-conscious cues may be picked up along the way. When one reaches the inside of the store, dead reckoning and localization are reinitialized for the new environment. Once you have reached the shopping area and start going up and down all the isles, the firing of the grid cells take dominance, along with the head direction cells. Spatial mapping is thus occurring.

From the neural cell descriptions and the example just given, we will now explain how these specialized navigational and spatial cognition cells are functionally mapped to hardware and software, as installed on the *ratbot*.

## THE RATBOT'S ARCHITECTURE

The *ratbot's* hardware components, connectivity, and functional relationship to the hardware's biological counter parts are now described, as illustrated in Figure 4b. Figure 5 shows a picture of the *ratbot* without the FPGA module installed. This configuration was used for the initial PI algorithm testing.

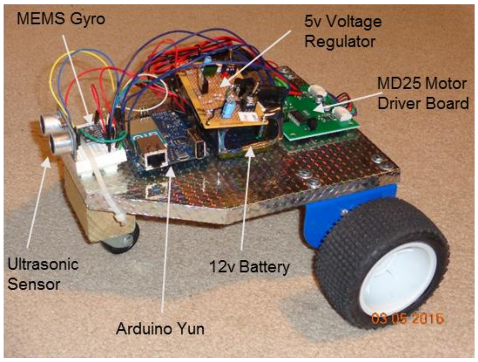


**Figure 5.** The ratbot and its hardware. The two 12v motors with encoders are not shown, but each motor connects to a rear wheel of the ratbot. Each motor is held into place by connecting to a (blue) bracket, as seen on the rear left side.

### A. Sensory Input

As described earlier, the sensory input to the ratbot's navigational system consists of three sensors:

- **Vision: Ultrasonic Sensor**

The HC-SR04 Ultrasonic Sensor is mounted to the front of the *ratbot* to simulate the rat's vision. Due to the limited capability of this sensor, which uses sound waves to detect obstacles up to 4 meters away, it will only be used for wall and obstacle avoidance. The starting coordinates of the *ratbot*, which will be explained shortly, will have to be used for determining its starting position. This will replace the initial search for external cues. The capability of finding visual cues will be implemented in the next iteration of the *ratbot*.

- **Vestibular organ of the inner ear: MPU6050**

The MPU6050 is a 6 degrees of freedom, MEMS based chip made by Invensense. This chip is also referred to as an inertial measurement unit (IMU). There is a tri-axis accelerometer and a tri-axis gyroscope on the IMU. Only data from a single axis of the gyroscope is used for the rat's head direction with respect to the horizontal plane. The gyroscope has a slow, steady drift, which is eliminated through a simple algorithm.

- **Proprioceptive stimuli: MD25 Motor driver board**

The two 12v motors, which are mounted on the rear of the ratbot, have encoders installed on them. These motors connect to an MD25 board, which is made by Robot Electronics (UK). The motors are driven by writing serial data from the main robot's microcontroller to the MD25 onboard Microchip PIC microcontroller, which then drives the H-Bridge amplifiers with pulse width modulated (PWM) signals. Wheel movement data, at 1 degree resolution, and a total of 360 degrees for a full turn of the wheel/motor, is accumulated for each motor in special register in the PIC microcontroller. The robot's main microcontroller can request these values for each wheel at any time. This represents the proprioceptive stimuli or motor feedback to the rat's brain.

## B. The Ratbot's "Brain"

From a neuroscience perspective, the circuitry in the above described input sensors would be considered as part of the rat's brain. However, for the *ratbot*, the main microcontroller and the FPGA will be considered as the robot's "brain".

### • I/O Interface and PI Calculator: Microcontroller

The microcontroller chosen for the *ratbot's* navigation part of the "brain" is the Arduino Yun. The Arduino Yun is a combination of an Atmel ATmega 32U4 microcontroller connected to an Atheros AR9331 processor, which runs a Linux distribution based on OpenWrt. This board was chosen over a less expensive Arduino microcontroller, due to the built in WiFi capabilities of the Yun. Thus, the Yun and a computer with a WiFi card can connect to each other via a shared WiFi hub. This is important for sending data from the *ratbot* to the PC for graphing and/or debugging purposes. Example debug data sent from the *ratbot* to the PC includes: direction data from the IMU, distance data from the motor encoders, turn commands, and calculated vector values.

When debug mode is not required, the Arduino Yun can be replaced with a much less expensive (both cost and power consumption wise) Arduino Uno microcontroller board. Both microcontroller boards have the same header pinouts, and the microcontroller software only requires two lines of code commented out (#define's) at the top of the program for compatibility with the Uno.

### • Environment Mapping/Spatial Awareness: FPGA

A Xilinx Spartan-6 FPGA is used for performing spatial awareness tasks (see Figure 4b for general data flow). The FPGA based platform used is made by Embedded Micro and is called Mojo, see Figure 6. The headers surrounding the perimeter of the Mojo are for the 84 digital I/O ports and 8 analog input ports.

The FPGA module receives vector data, object detection data, and a stop indicator signal from the central microcontroller (Yun/Uno). This information is used by the biologically inspired grid cell and its logically mapped, lattice firing regions in the FPGA. Thus, the logic and registers in the aggregate instantiated firing regions of a grid cell, replaces the use of a single grid cell connected to a complex artificial neural network (ANN). The advantage to this method is the ability to quickly update and retrieve mapped locations through the use of parallel processing. The grid cell firing regions process the input data from the microcontroller in parallel, saves information about locations of objects detected, and uses this information later during path planning.

Greater detail on how PI and spatial awareness is achieved in the *ratbot's* "brain" and sensory system is described next.

**Figure 6.** The Mojo by Embedded Micro. The on-board Xilinx Spartan-6 FPGA is used for the implementation of grid cells and their firing regions.

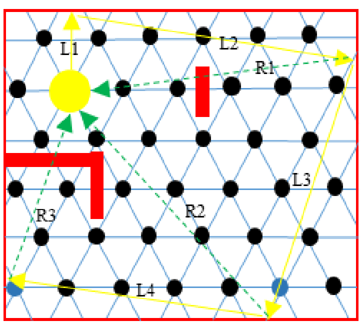


**Figure 7.** An example environment and travel scenario of the ratbot. The black dots represent a single grid cell's firing region, which is mapped to the environment ratbot's environment. The yellow dot is the ratbot's home (start and ending position). The yellow arrows (Rn) represents a travel leg of the journey. The green dashed arrows are the return vectors calculated along the way (PI). The red rectangles represent barriers, and the blue dots represent a pseudo barrier cell with directional information.

## NAVIGATION ALGORITHM

As discussed previously, the goal of the *ratbot* is to simulate a rat leaving its home, go foraging (making a preset number of collision avoidance turns), then return back to its home. Therefore, the performance of the navigational system will be based on how closely the robot returns to its initial starting position (home).

In the *ratbot*, path integration is easily achieved using the law of sines and cosines on the measured angle and relative distance traveled respectively. Therefore, the first return vector is calculated after the first two legs of the foraging journey (in Figure 7, R1 is the return vector calculated from the direction and distance measured for L1 and L2). Thereafter, a return vector is calculated at the end of each additional leg of the journey. Figure 7 represents the data processing that is occurring in the microcontroller and FPGA combined. For example, PI is occurring in the microcontroller, while initialization of grid cell firing region instances (this includes coordinates given to each firing node or instance, and the spacing between firing nodes), mapping, error checking, conversion of grid cell firing region instance to border cell with barrier relative direction information, etc. occurs in the FPGA.

## IMPLEMENTATION AND RESULTS

The *ratbot* currently performs PI with only minor return distance error (small percent of total distance traveled). As expected, the error grows with each additional waypoint added to the *ratbot's* journey. The configured decision making that the *ratbot* performs at each barrier reached, is to turn approximately 110$^{\circ}$ to the right, then proceed forward if there is no blockage. Otherwise it will continue to turn right and check for blockage. The flow chart shown in Figure 8 gives further details on the currently implemented PI algorithm, and represents the software which runs on the central microcontroller of the *ratbot*. For visual simplification, Figure 8 shows all of the return vectors being calculated just prior to the *ratbot* heads back home, rather than at each waypoint as previously described.

As of writing this paper, the FPGA's programming and interfacing to the central microcontroller is currently being performed. The testing that will be performed once the FPGA's design and integration is completed will be to compare various environment scenarios (e.g., as illustrated in Figures 1, 3 & 7), along with a range of waypoints, to see how much, if any, the spatial cognition inspired algorithm adds to the *ratbot's* foraging performance.

## OTHER POSSIBLE RELATED RESEARCH

As compared to the self-driving car example or any robot with complex external stimuli sensor, the *ratbot* uses a more simplistic navigational system, from a sensor fusion perspective [5, 30], due to the minimum number of sensors used. Minimizing the number of sensors allows for greater focus on the analysis of the *ratbot's* neuro-biologically inspired navigational system (i.e., PI), as opposed to the sensory systems themselves. In particular, a very limited visual system is employed, thus making the *ratbot's* navigation algorithm more dependent on internal stimuli, rather than external stimuli. If the navigation system had strong visual recognition capabilities, then the importance of the internal stimulus would be over shadowed. This is based on the assumption of there being many unique salient distal cues along the robot's path, as well as the visual based sensors and algorithms capable of picking them out. However, the impact of adding better visual capabilities to the navigation system will be addressed in the future work section of this paper.

The *ratbot's* low visibility capable navigation system, could easily represent individuals with poor-to-no visual capabilities, or individuals in poor visibility settings. For example, having the *ratbot* emulate individuals with poor/no visual capabilities, could be useful for investigating city architectures/layouts for the blind [31, 32], as well as all pedestrians in some cases. The same would apply to the *ratbot* emulating an individual in low visibility environments, such as those found in building fires. Thus, how well an autonomous robot, which is equipped with our proposed navigation system, could be used for indoor search and rescue purposes during building fires [33], would also be an applicable application.

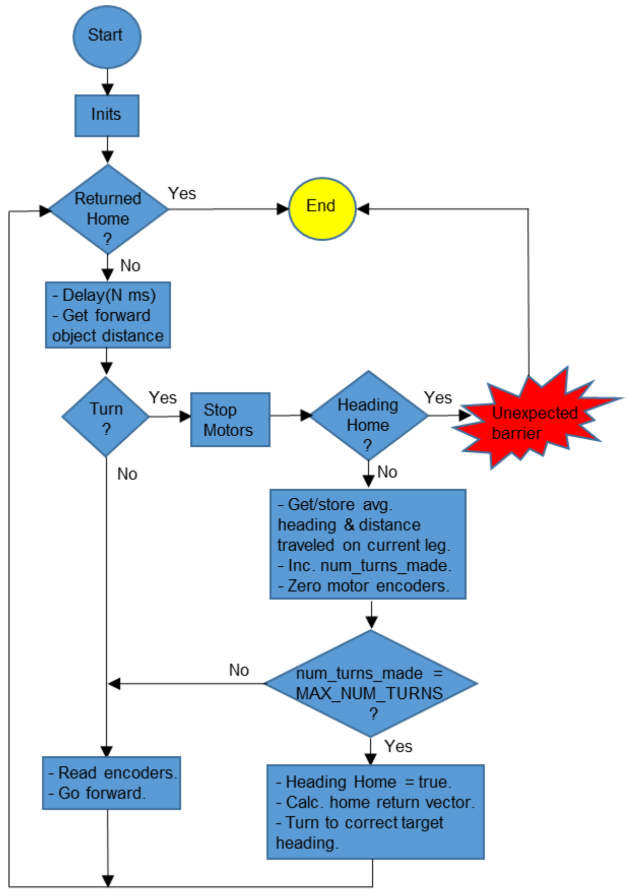


**Figure 8.** Flow chart of PI program which runs on the *ratbot's* central microcontroller.

## CONCLUSIONS AND FUTURE WORK

As with some similar mobile robot systems which use a neuro-biological inspired navigational system, such as the RatSLAM [34, 35], some consolidation and modifications had to be made to a neural navigation cell's original functionality. In the case of the *ratbot*, it was sensible to have a grid cell's firing region/node morph into a border cell with directional information when a barrier was detected. This allows for the node to relate information back to the grid cell itself, information about obstacles or barriers in the direction and path of the return vector. Additionally, width had to be added to the return path search, to deal with the space between nodes.

Future work will include upgrading the *ratbot's* visual capability. This will most likely be accomplished through the use of a simple camera and algorithm for object detection and recognition. The Arduino based microcontroller board will likely need to be upgraded to a RaspberryPi board, which uses an Arm 700MHz processor and has much more main memory, as well as off chip memory. The mapping will still be performed by the FPGA for its parallel processing capability, which emulates the way the brain works. Additionally, increasing the ratbot's foraging distance and complexity, such as adding the ability for the map information to roll over from one local area to another, will also be addressed.

## REFERENCES

[1] T. Drage, J. Kalinowski, and T. Braunl, "Integration of Drive-by-Wire with Navigation Control for a Driverless Electric Race Car," *Intelligent Transportation Systems Magazine, IEEE,* vol. 6, pp. 23-33, 2014.
[2] J. Wang, C. Zhang, Y. Shan, Y. Xu, and S. Wang, "Research on Key Technologies for Urban Unmanned Intelligent Vehicle," in *Intelligent Systems (GCIS), 2010 Second WRI Global Congress on*, 2010, pp. 51-54.
[3] M. Gerla, L. Eun-Kyu, G. Pau, and L. Uichin, "Internet of vehicles: From intelligent grid to autonomous cars and vehicular clouds," in *Internet of Things (WF-IoT), 2014 IEEE World Forum on*, 2014, pp. 241-246.
[4] B. Bischoff, N.-T. Duy, F. Streichert, M. Ewert, and A. Knoll, "Fusing vision and odometry for accurate indoor robot localization," in *Control Automation Robotics & Vision (ICARCV), 2012 12th International Conference on*, 2012, pp. 347-352.
[5] A. Elkady, V. Babariya, J. Joy, and T. Sobh, "Modular Design and Structure for a Mobile Sensory Platform," in *Technological Developments in Networking, Education and Automation*, ed: Springer, 2010, pp. 433-441.
[6] B. L. McNaughton, F. P. Battaglia, O. Jensen, E. I. Moser, and M.-B. Moser, "Path integration and the neural basis of the'cognitive map'," *Nature Reviews Neuroscience,* vol. 7, pp. 663-678, 2006.
[7] J. L. Kubie and A. A. Fenton, "Heading-vector navigation based on head-direction cells and path integration," *Hippocampus,* vol. 19, pp. 456-479, 2009.
[8] M. Müller and R. Wehner, "Path integration in desert ants, Cataglyphis fortis," *Proceedings of the National Academy of Sciences,* vol. 85, pp. 5287-5290, 1988.
[9] N. Burgess and J. O'Keefe, "Neuronal computations underlying the firing of place cells and their role in navigation," *Hippocampus,* vol. 6, pp. 749-762, 1996.
[10] T. Hartley, N. Burgess, C. Lever, F. Cacucci, and J. O'Keefe, "Modeling place fields in terms of the cortical inputs to the hippocampus," *Hippocampus,* vol. 10, pp. 369-379, 2000.
[11] J. O'keefe and D. Conway, "Hippocampal place units in the freely moving rat: why they fire where they fire," *Experimental Brain Research,* vol. 31, pp. 573-590, 1978.
[12] J. O'Keefe and J. Dostrovsky, "The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat," *Brain research,* vol. 34, pp. 171-175, 1971.
[13] T. J. Wills, F. Cacucci, N. Burgess, and J. O'Keefe, "Development of the Hippocampal Cognitive Map in Preweanling Rats," *Science,* vol. 328, pp. 1573-1576, June 18, 2010 2010.
[14] M. Fyhn, S. Molden, M. P. Witter, E. I. Moser, and M.-B. Moser, "Spatial representation in the entorhinal cortex," *Science,* vol. 305, pp. 1258-1264, 2004.
[15] T. Hafting, M. Fyhn, S. Molden, M.-B. Moser, and E. I. Moser, "Microstructure of a spatial map in the entorhinal cortex," *Nature,* vol. 436, pp. 801-806, 2005.
[16] H. Stensola, T. Stensola, T. Solstad, K. Frøland, M.-B. Moser, and E. I. Moser, "The entorhinal grid map is discretized," *Nature,* vol. 492, pp. 72-78, 2012.
[17] S.-J. Zhang, J. Ye, C. Miao, A. Tsao, I. Cerniauskas, D. Ledergerber*, et al.*, "Optogenetic dissection of entorhinal-hippocampal functional connectivity," *Science,* vol. 340, p. 1232627, 2013.
[18] J. S. Taube, "The head direction signal: origins and sensory-motor integration," *Annu. Rev. Neurosci.,* vol. 30, pp. 181-207, 2007.
[19] J. S. Taube, R. U. Muller, and J. B. Ranck, "Head-direction cells recorded from the postsubiculum in freely moving rats. I. Description and quantitative analysis," *The Journal of Neuroscience,* vol. 10, pp. 420-435, 1990.
[20] C. Darwin, "Origin of Certain Instincts," *Nature,* vol. 7, pp. 417-418, 1873.
[21] H. Mittelstaedt and M.-L. Mittelstaedt, "Homing by path integration," in *Avian navigation*, ed: Springer, 1982, pp. 290-297.
[22] A. Arleo and W. Gerstner, "Spatial cognition and neuro-mimetic navigation: a model of hippocampal place cell activity," *Biological Cybernetics,* vol. 83, pp. 287-299, 2000.
[23] Y. Burak and I. R. Fiete, "Accurate path integration in continuous attractor network models of grid cells," *PLoS computational biology,* vol. 5, p. e1000291, 2009.
[24] D. Samu, P. Erős, B. Ujfalussy, and T. Kiss, "Robust path integration in the entorhinal grid cell system with hippocampal feed-back," *Biological cybernetics,* vol. 101, pp. 19-34, 2009.
[25] J. W. Yeol, "An Improved Position Estimation Algorithm for Localization of Mobile Robots by Sonars," in *Engineering Sciences and Technology, 2005. SCONEST 2005. Student Conference on*, 2005, pp. 1-5.
[26] K. Kyoung-Dong, K. Yoon-Gu, A. Jinung, X. Zhi-Guang, and L. Suk-Gyu, "Enhanced localization for team robot navigation using compass sensor and USN," in *Control Automation and Systems (ICCAS), 2010 International Conference on*, 2010, pp. 91-95.

[27] P. Stratton, M. Milford, G. Wyeth, and J. Wiles, "Using strategic movement to calibrate a neural compass: A spiking network for tracking head direction in rats and robots," *PloS one*, vol. 6, p. e25687, 2011.
[28] C. F. Doeller, C. Barry, and N. Burgess, "Evidence for grid cells in a human memory network," *Nature*, vol. 463, pp. 657-661, 2010.
[29] D. Bush, C. Barry, and N. Burgess, "What do grid cells contribute to place cell firing?," *Trends in neurosciences*, vol. 37, pp. 136-145, 2014.
[30] G. T. Sibley, M. H. Rahimi, and G. Sukhatme, "Robomote: a tiny mobile robot platform for large-scale ad-hoc sensor networks," in *Robotics and Automation, 2002. Proceedings. ICRA '02. IEEE International Conference on*, 2002, pp. 1143-1148.
[31] O. Lahav and D. Mioduser, "A blind person's cognitive mapping of new spaces using a haptic virtual environment," *Journal of Research in Special Educational Needs*, vol. 3, pp. 172-177, 2003.
[32] O. Lahav and D. Mioduser, "Haptic-feedback support for cognitive mapping of unknown spaces by people who are blind," *International Journal of Human-Computer Studies*, vol. 66, pp. 23-35, 2008.
[33] J. Sales, R. Marín, E. Cervera, S. Rodríguez, and J. Pérez, "Multi-sensor person following in low-visibility scenarios," *Sensors*, vol. 10, pp. 10953-10966, 2010.
[34] M. J. Milford, G. F. Wyeth, and D. Prasser, "RatSLAM: a hippocampal model for simultaneous localization and mapping," in *Robotics and Automation, 2004. Proceedings. ICRA '04. 2004 IEEE International Conference on*, 2004, pp. 403-408 Vol.1.
[35] G. Wyeth and M. Milford, "Spatial cognition for robots," *Robotics & Automation Magazine, IEEE*, vol. 16, pp. 24-32, 2009.

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# Development of a Voltammetric Sensor for Detecting Metals in Water

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## Abstract

Elevated concentrations of heavy metals in water present a significant toxicity and health risk. A simple method for onsite, quantitative electrochemical analysis of water is presented here. Square wave stripping voltammetry experiments were conducted using a glassy carbon electrode to determine concentrations of lead and cadmium in water. Additionally, a miniature potentiostat and data acquisition software were developed to allow for the onsite deployment of this technology. The electrochemical system was capable of detecting lead and cadmium down to the maximum contamination level specified by the Environmental Protection Agency. Statistical methods were used to generate mathematical models for analysis of results. The authors also participated in the National Science Foundation Innovation Corps Program, where they received training in entrepreneurship. With this training, the authors determined the markets where they would be selling the voltammetric sensor, to refocus the research and development to address the greatest market needs.

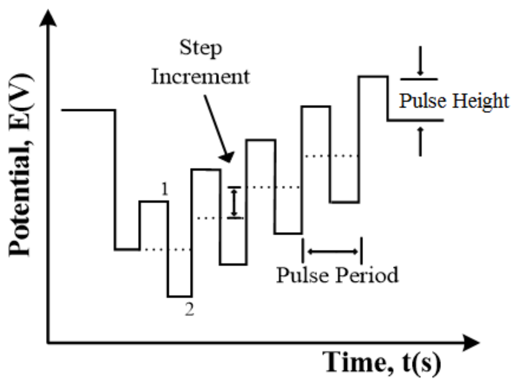
## Keywords

Voltammetry, Sensor, Heavy Metals, Commercialization

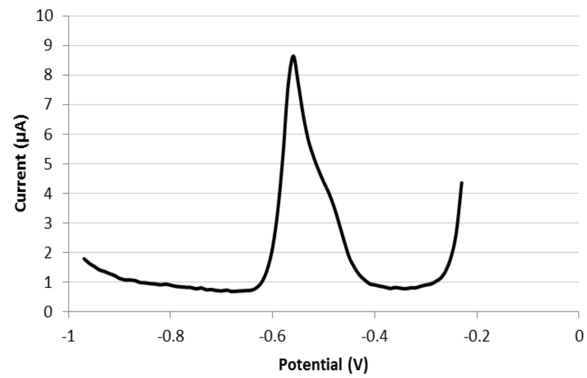
## Introduction

Elevated concentrations of heavy metals in surface water, groundwater, and sediment pore water are a major environmental concern. Exposure to high levels of heavy metals can result in a range of ailments, including damage to the nervous system, gastrointestinal system, kidneys, and liver. Lead and cadmium are among the most toxic heavy metals, with EPA maximum contamination levels of 15 ppb for lead and 5 ppb for cadmium.[1] Current methods of heavy metal detection involve sampling the contaminated media, and subsequent transport to a laboratory for testing using large benchtop devices such as inductively coupled plasma mass spectrometers and atomic absorption spectrometers. This approach presents the risk of exposure of highly toxic media to field workers and laboratory personal and significantly increases the costs associated with site characterization. An in-situ testing method for quantitative analysis of contaminated water would significantly reduce both the risk and cost associated with testing for heavy metal contamination.[2]

Voltammetry can be used for the qualitative and quantitative analysis of electroactive species in aqueous media. Voltammetry is performed by controlling the electrical potential at a system of electrodes and measuring the changes in current, using a device known as a potentiostat. The electrode system consists of one or more working electrodes, where the reaction of interest occurs, an auxiliary electrode, which provides the second half of redox reaction required for current to flow, and a reference electrode, which provides a reference point for the measurement of potential. From the analysis of the resulting plot of current versus potential, known as a voltammogram, the type and concentration of metal ions in solution can be determined from the location (specific voltage on the voltammogram) and magnitude of peak current, respectively.[3]




(a)



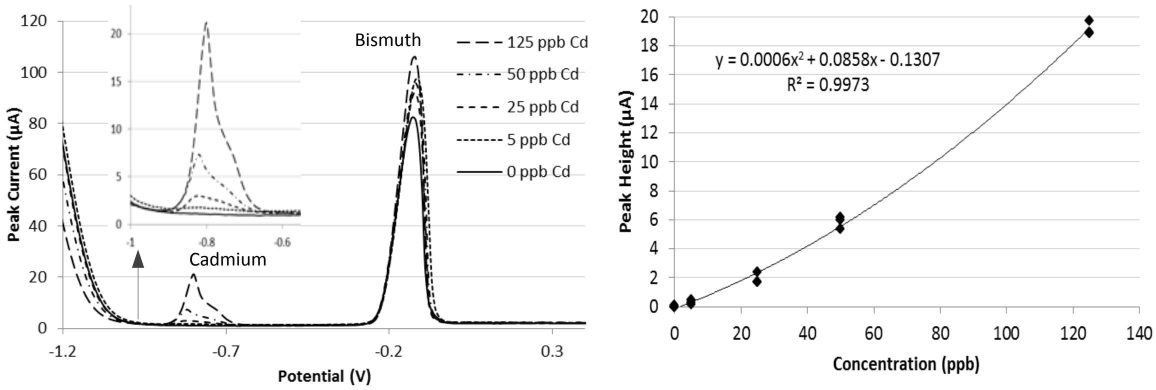

(b)

Figure 1: (a) Example wave-form and (b) example voltammogram for a SWSV test.

One of the most common voltammetric tests is square wave stripping voltammetry (SWSV). The SWSV tests consist of two stages, a deposition period and a sweeping period. During the deposition period, the working electrode is held at a constant negative potential to deposit metallic ions onto the surface of the electrode. During the sweeping period, the baseline potential is increased and constant periodic increases in potential are superimposed on the baseline current (see Figure 1). The current is measured before and after the increase in potential and the difference of these two values is taken as the current reading. Peaks in current occur when an electroactive species is oxidized at the working electrode and correlations can be developed between peak features and ion species or concentration. [4]

## Development of the Voltammetric Sensor System

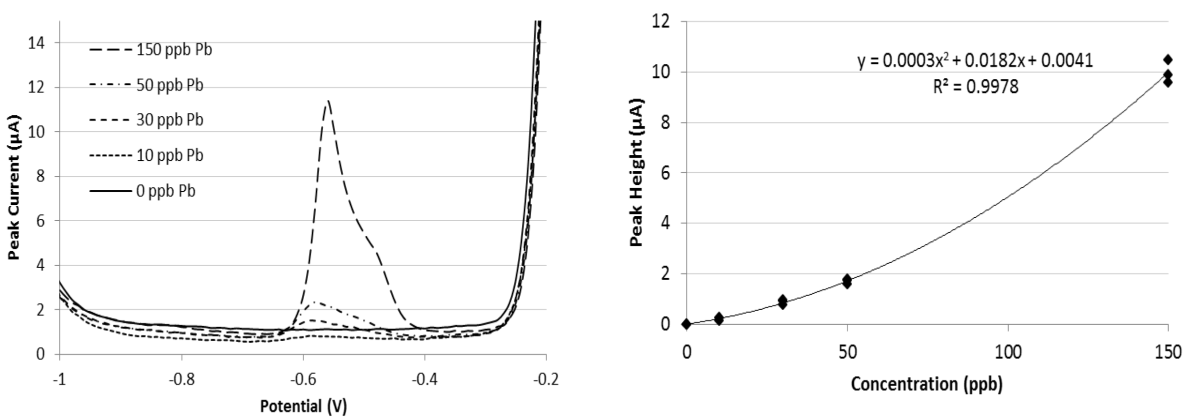
SWSV experiments were conducted using a three electrode system to measure concentrations of lead and cadmium in samples of water. The system of electrodes consisted of a glassy carbon working electrode, a silver/silver chloride reference electrode, and a platinum auxiliary electrode. All electrical potentials reported are taken with respect to the silver/silver chloride reference electrode. The preliminary SWSV experiments were performed with a commercially purchased WaveNow potentiostat manufactured by Pine Instruments. A waveform with amplitude of 75 mV, period of 150 ms, sampling width of 5 ms and increment of 10 mV was used for the electrochemical measurements. A deposition time of 30 minutes and a deposition potential of -1 V were used.




(a) (b)

Figure 2: (a) Voltammograms and (b) Regression model for cadmium in deionized water with concentrations ranging from 0 ppb to 125 ppb.

Prior to each test all electrodes were cleaned with methanol and deionized water and the working electrode was polished using 0.05 µm alumina polish. Five milliliters samples with a known concentration of lead or cadmium were prepared with deionized water. Five milliliters of pretreatment solution was then added to the samples, bringing the final volume to 10 mL. The pretreatment solution gave the final sample a 100 mM acetate buffer and 4 µM concentration of bismuth nitrate. Solution concentrations of lead ranging from 0 to 150 ppb, and cadmium ranging from 0 to 125 ppb were tested.




(a) (b)

Figure 3: (a) Voltammograms and (b) Regression model for lead in deionized water with concentrations ranging from 0 ppb to 150 ppb.

The resulting voltammograms were analyzed to determine the peak currents and corresponding formal potentials (see Figure 2 and Figure 3). All voltammograms had two peaks, corresponding to the bismuth in the pretreatment solution and the analyte of interest. The peaks for cadmium, lead, and bismuth were observed at potentials of -0.82 V, -0.58 V, and -0.12 V, respectively. The bismuth peak height was not influenced by the concentration of lead and cadmium and, as seen in Figure 2 (a), was approximately an order of magnitude higher than the lead and cadmium peaks. For these reasons, the bismuth peaks are not included in the subsequent voltammograms. Regression curves were produced to determine the relationship between peak height and concentration. The regression curves had $R^2$ values of 0.9973 for lead and 0.9978 for cadmium. Additionally, a decision tree model was developed to classify the target ion based on peak formal potential (See Figure 4). The model classified the peaks with 100% accuracy under 15-fold cross validation.

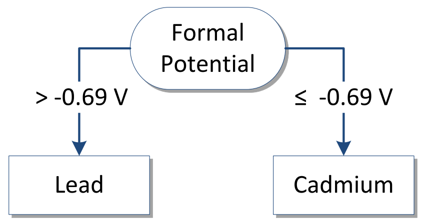
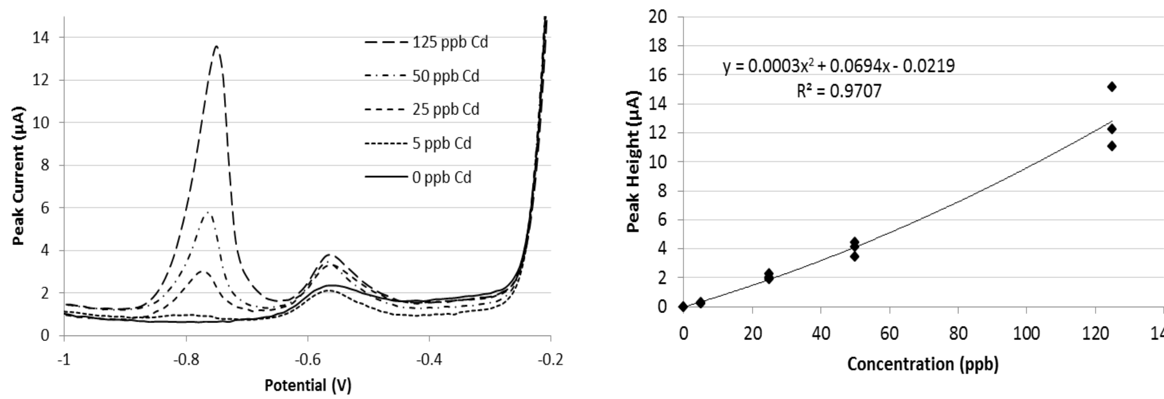



Figure 4: Decision tree for the qualitative analysis of lead and cadmium in deionized water.

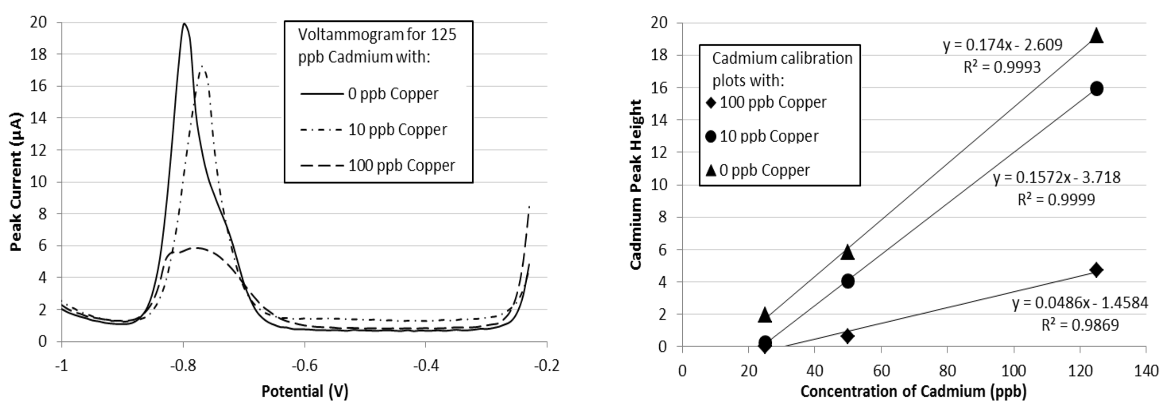
To determine the performance of the sensor in real world applications, samples of groundwater spiked with concentrations of cadmium ranging from 0 ppb to 125 ppb were tested. All samples of groundwater were gathered from a monitoring well in Lowell, Massachusetts, with the help of the Massachusetts Department of Enviromental Protection. Prior to sample preperation, the groundwater was tested by an outside laboratory for heavy metals. The results showed no preexisting lead or cadmium in the sample. After being spiked with cadmium, the samples were prepared and tested following the same procedure as the samples prepared with deionized water. The volammetric results (see Figure 5) showed three peaks, occurring at potentials of -0.75 V, -0.57 V, and -0.13 V. The peak at -0.13 V corresponded to bismuth, and the unknown peak at -0.57 V remained constant for all samples. The peak at -0.75 V increased with increasing cadmium concentration. A regression analysis of the cadmium peak heights produced a model with a $R^2$ value of 0.9707. When compared to the peak heights observed in deionized water, the responses in groundwater at 50 ppb and 125 ppb was significantly lower in magnitude. However at lower concentrations (0 ppb to 25 ppb) the peak heights were not significantly affected and the limit of detection was not impacted. The decrease in peak height at higher concentrations is believed to be caused by binding of the cadmium with organic material in the groundwater.




(a) (b)

Figure 5: (a) Voltammograms and (b) Regression model for cadmium in groundwater with concentrations ranging from 0 ppb to 125 ppb.

Additionally, samples were tested with various concentrations of copper, to determine the impact of copper on sensor responses. Copper was chosen as the potential interference, because copper is commonly found in drinking water and other real world samples. Samples of water with concentrations of cadmium ranging from 25 ppb to 125 ppb and concentrations of copper ranging from 0 ppb to 100 ppb were tested. The experiments were performed using the same sample preparation and methodology as the previous tests. The results of this analysis (see Figure 6) showed a decrease in cadmium peak height with increasing concentrations of copper. This decrease was attributed to the copper ions competing with the cadmium ions for space at the surface of the working electrode. Despite this interference, the cadmium peak height and cadmium concentration were still highly correlated, indicating that a model or correction factor based on the concentration of copper could be developed to account for the interference.




(a) (b)

Figure 6: (a) Voltammograms for 125 ppb of cadmium tested with concentrations of copper ranging from 0 ppb to 100 ppb and (b) Regression models for cadmium with concentrations ranging from 0 ppb to 125 ppb with concentrations of copper ranging from 0 ppb to 100 ppb.

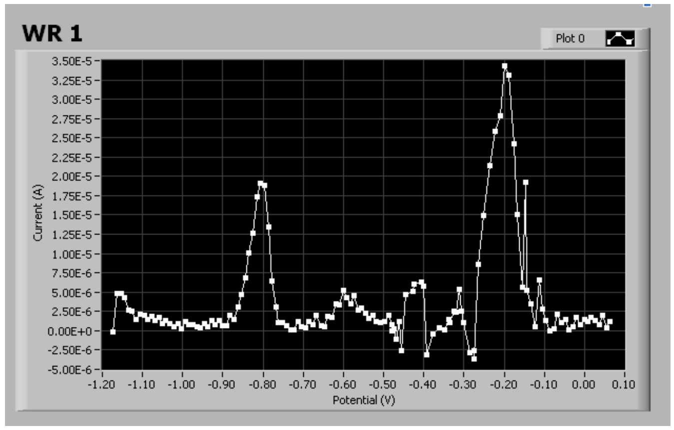



Figure 7: Voltammogram obtained with the UMass Lowell developed potentiostat and data acquisition software.

A custom fabricated potentiostat, data acquisition and interpretation software were developed to allow for the onsite implementation of this technology. The programs for data acquisition, visualization and interpretation were developed with LabVIEW System Design Software from National Instruments (Figure 7). To test the software and potentiostat a series of tests were run with cadmium concentrations ranging from 0 ppb to 125 ppb. All experimental parameters were kept the same with the exception of the period, which was increased to 250 ms to decrease the noise present in the voltammograms. The results showed peaks with a comparable height to the tests run with the commercial potentiostat. The peaks corresponding to cadmium and bismuth were observed at potentials of -0.82 V and -0.19 V, respectively (Figure 8a). A regression model was fitted to the data, with an $R^2$ value of 0.9917 (Figure 8b).

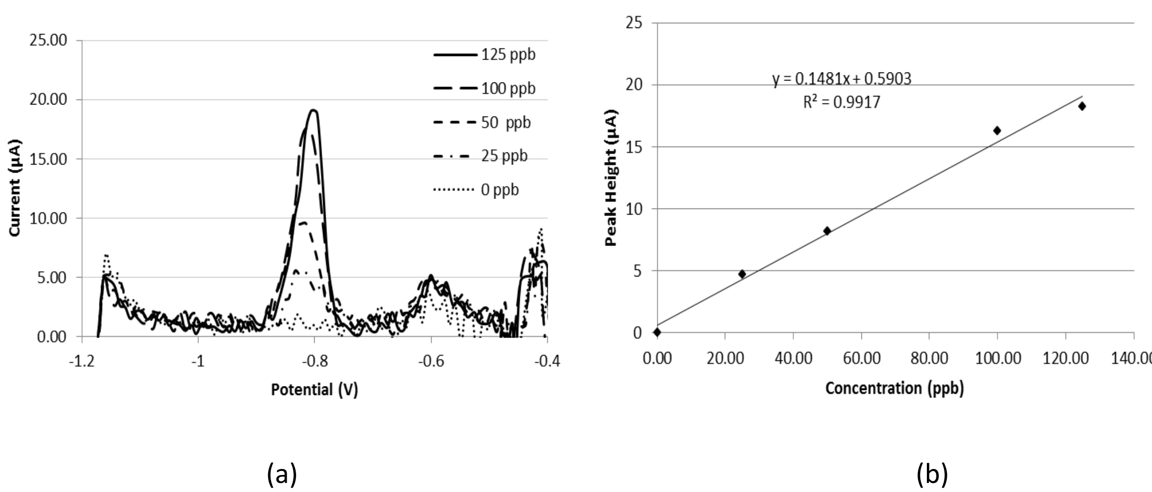



Figure 8: (a) Voltammograms and (b) Regression model for cadmium, with concentrations ranging from 0 ppb to 125 ppb tested with the UMass Lowell developed potentiostat.

## Commercialization Potential Research

Following the completion of the preliminary research for this project, the authors participated in the National Science Foundation Innovation Corps Program (NSF I-Corps), where they received training in entrepreneurship. Through the process of NSF I-Corps, the authors developed a business model for a potential startup and conducted 105 customer interviews. Once the customer segments were identified, subsequent interviews then focused on gaining additional information about the value the company would offer, the infrastructure needed, and the financial viability of the company. As the team conducted interviews, the team's hypotheses about the market were tested and updated using an iterative method (see Figure 9). During this iterative process, the information gathered was organized in a visual chart known as the business model canvas. The business model canvas is a strategic management and lean startup template which contained the team's hypothesis about the market. As the customer interview process progressed, the initial hypotheses were confirmed, modified (to reflect the reality of the market), or invalidated.

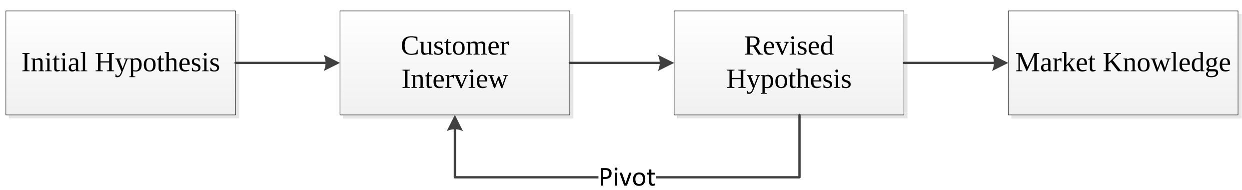



Figure 9: Flow diagram of iterative method used during the customer interview process.

The authors initially assumed that the sensor system would have applications in nearly all segments of environmental engineering dealing with water or soil. These potential customer segments included environmental engineers working in the remediation of groundwater, sediments, and soil, engineers and regulators overseeing drinking water and wastewater facilities, environmental laboratory directors, and managers of industrial wastewater producers. In addition to interviewing potential customers, the authors interviewed distributors, regulators, and manufactures in the environmental instrument market to gain information on how the market ecosystem works and what barriers to entry exist.

During the customer discovery process, three addressable markets were identified. Environmental engineers working in the remediation of contaminated sediments have a need for a technology to test pore water onsite to determine if the sampling of sediments is being done efficiently. Current technology has not addressed this market because the turbidity of the samples prevents accurate results with current portable devices. The voltammetric sensor would allow environmental engineers to test samples of pore water onsite, thereby addressing this pain point. Additionally, managers of industrial wastewater producers have a need to test their wastewater to ensure they are in compliance with regulations. Portable colorimeters are being sold to this market but these devices are not widely used and the potential exists for the voltammetric sensor to expand into this market once it has become an established product. Finally, environmental engineers working at environmental regulatory agencies are interested in having a device for the long term monitoring of heavy metals in groundwater monitoring wells and surface water. The engineers at these agencies are interested in gathering additional data for the evaluation of remediation techniques, government policy, and individual company performance.

As customer segments were identified, the value propositions for each market were determined. The main value proposition of the voltammetric sensor for environmental engineers remediating sediments is the on-site testing capability that significantly reduces time (from weeks to minutes) to receive information about the distribution and concentration of contamination at a site. The main value proposition for managers of industrial wastewater producers is the decreased risk of violating government regulations. The main value proposition for environmental engineers at government agencies is the increased amount of data gathered.

With the information and training gained during the NSF I-Corp Program, the authors have redirected their research to address the greatest market need, in order to maximize the likelihood of producing a commercially viable product. The authors' research efforts have been refocused on optimizing the voltammetric sensor to meet the needs of the customer segments. Additionally the authors have contacted potential end users and manufactures with the intention of validating the technology and eventually bringing the voltammetric sensor to market.

## Conclusions

This research has investigated the potential of a voltammetric sensor for the detection of heavy metals in contaminated water. The decision tree model that was developed to classify the target ion based on peak formal potential classified the peaks with 100% accuracy. The regression curves to determine the heavy metal concentrations from the peak heights, had $R^2$ values of 0.9973 for lead and 0.9978 for cadmium. Based on the customer interviews conducted, there are several markets that this technology could be sold to, within the environmental engineering and regulatory fields. This information will be critical in further development of this technology.

## References

1 National Primary Drinking Water Regulations, US E.P.A., 1200 Pennsylvania Avenue, N.W. Washington, D.C., 2009, 1-5.

2 Robertson, Seth; Timothy Ponrathnam; Junghwan Cho, Ramaswamy Nagarajan and Pradeep Kurup, Voltammetric Detection of Cadmium in Groundwater, GeoCongress, 2012, 3390-3397.

3 Kurup, Pradeep; Seth Roberson; Junghwan Cho, and Ramaswamy Nagarajan, Laboratory Calibration of a Hybrid Electronic Tongue for the Cone Penetrometer, International Symposium on Cone Penetration Testing (CPT), Las Vegas, NV, 2014, 249-256.

4 Kounaves, Samuel, Handbook of Instrumental Techniques for Analytical Chemistry, Prentice Hall PTR, Upper Saddle River, NJ, 1997, 709-725.

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