Impact of Nanoscale Science and Engineering Course on the Undergraduate Engineering Education

Dr. Ozgul Yasar-Inceoglu, California State University, Chico

Ozgul Yasar-Inceoglu is an Assistant Professor in Mechanical and Mechatronic Engineering and Sustainable Manufacturing Department at California State University, Chico. She received her Ph.D in Mechanical Engineering from University of California, Riverside and her MS. degree in Materials Science from Norfolk State University. Her research interests includes synthesizing and characterization of nanoparticles and nanoparticles-based devices.

IMPACT OF NANOSCALE SCIENCE AND ENGINEERING COURSE ON THE UNDERGRADUATE ENGINEERING EDUCATION

ABSTRACT

Nanoscience and nanotechnology play a significant role in every field of our society. Nanotechnology is the backbone of high-tech industries and widely used in consumer products and industrial applications. Therefore, it is essential to highlight the importance of nanoscience and nanotechnology to undergraduate students and explain the science behind it. For this purpose, an upper-level elective Mechanical Engineering course, Nanoscale Science and Engineering, is designed and added to the Mechanical and Mechatronic Engineering curriculum. This course introduces students to the interdisciplinary field of nanoscience and engineering including the areas of engineering, materials science, chemistry, and physics. The topics covered include advanced materials, synthesis, and modification of nanomaterials, properties of nanomaterials, materials characterization, nanofabrication methods, and applications. It has three modules, which are formal lectures, guest speakers, and projects.

The impact of the Nanoscale Science and Engineering course on undergraduate Mechanical and Mechatronic Engineering students was assessed through a survey performed at the beginning and end of the semester. The survey questions were aimed to analyze the awareness, motivation, and retention of the students in the nanotechnology field. Statistical analysis showed that students' awareness, motivation, and retention in nanotechnology increased. The impact of the course on students' perspective were also evident in their written comments.

The majority of the students in California State University, Chico are first generation students and come from minority communities. This course was their first exposure to fundamental and application of nanotechnology. The inclusion of Nanoscale Science and Engineering course to the undergraduate engineering curriculum has a significant role in the advancement of nanotechnology. Students graduating with a solid understanding of broad applications of nanotechnology and advanced material fabrication and characterization techniques will have a focused start in their graduate research and education or faster adaptation to nanotechnology-related industrial job positions.

1. INTRODUCTION

Nanotechnology is a new, fast-developing, and cutting-edge field in engineering and science. It is is an important concept that positively affects the economy, environment, and every field of our society. Nanotechnology is also the backbone of high-tech industries and widely used in consumer products and industrial applications.

It can be considered as industrial revolution and also the fastest growing industry in history. In early 2000’s United State (US) government spent more than $422 million on nanotechnology research and development[1-3]. The US National Nanotechnology Initiative’s (NNI) member agencies such as National Science Foundation (NSF), Department of Energy (DOE), Department of Defense (DOD), National Institute for Health (NIH), Department of Justice (DOJ), and Environmental Protection Agency (EPA) have spent $25 billion since 2001. For the NNI, the requested amount is over $1.4 billion for 2020, which help founding of major interdisciplinary research centers creating new job opportunities.

Although nanotechnology has been well embedded in engineering education at graduate level, it is important to introduce nanotechnology to undergraduate engineering students since many of them will join the workforce after graduation without entering in an advanced degree program[4, 5]. Therefore, increasing the awareness about nanotechnology and providing the students with fundamental knowledge of nanoscience and applications would be helpful to prepare them for their career[6]. Engineering graduates, especially in Northern California, with a knowledge of nanofabrication and characterization techniques will be advantaged in job search, be better prepared for handling tasks if they join a high-tech industry, and may be more motivated for advancing their knowledge and skills in a nano-related field. In addition, Nanotechnology is an effective way to introduce students to interdisciplinary sciences[7]. Therefore, in order to introduce nanoscience and nanotechnology to undergraduate Mechanical and Mechatronic Engineering students, an upper-level elective course, Nanoscale Science and Engineering MECH 430, has been designed and added to the Mechanical and Mechatronic Engineering curriculum at California State University, Chico. The success of this course and the impact of nanoscale science and engineering were analyzed through a Nanotechnology Survey [5, 8, 9].

The purpose of this paper is to describe the awareness and motivation of undergraduate engineering students on nanotechnology and the impact of Nanoscale Science and Engineering course on undergraduate engineering students.

This paper is organized as follows: section 2 describes the details about the designed course and nanotechnology survey, section 3 presents the collected data, which is discussed in section 4. The last section presents the conclusion and acknowledgements.

2. METHODS

2.1.Course Description and Design

A Nanoscale Science and Engineering course was designed as an upper-level technical elective course and added to the Mechanical and Mechatronic Engineering curriculum in Spring 2019. It was offered in Fall 2019 semester for the first time and had 22 enrolled students.

This course was designed to introduce the interdisciplinary field of nanoscience and nanotechnology, including engineering, materials science, chemistry, and physics, to undergraduate students. The topics covered include advanced materials, synthesis and modification of nanomaterials, properties of nanomaterials, materials characterization, nanofabrication methods, and applications (Table 1). The objectives of this course were to introduce the fundamentals of nanoscience and engineering to engineering, physics, and chemistry students and to provide opportunities for students to learn, study, and interact through interdisciplinary applications. The course had three hours of lecture per week. Contact hours consisted of formal lectures, guest speakers from both industry and academia, lab activities, and individual and group projects. Formal lectures were generally delivered via instructors Powerpoint slides prepared through nanotechnology textbooks, journal articles, video media, personal experience, etc. Nanomaterial characterization techniques lectures had both theory and experimentation, where students observed microscopic and spectral analysis of the

Table 1: Nanoscale Science and Engineering (MECH 430) course lecture topics

Nanoscale Science Engineering
Historical perspective of nanomaterials
Advanced materials
Materials, structure, and nanosurface
Energy at nanoscale
Nanoscience phenomena, bulk to quantum properties
Characterization techniques
X-ray Diffraction (XRD)
Scanning Electron Microscopy (SEM)
Energy Dispersive Spectroscopy (EDS)
Transmission Electron Microscopy (TEM)
Atomic Force Microscopy (AFM)
Raman Spectroscopy
Fourier-Transform Infrared Spectroscopy (FTIR)
Fabrication methods of nanomaterials, "bottom-up", "top-down" fabrication
Chemical synthesis and modification of nanomaterials
Non-thermal plasma technique to synthesize nanomaterials
Nano-electro mechanical structures (NEMS)
Applications

nanomaterials. These observational laboratory activities were designed to engage students [10]. Guest lecturers met students either in person or through a long-distance video conference. During the projects, students learned conducting literature search on a given topic and were asked to present their project. They further had a chance to propose their own ideas for potential applications and were asked to give a detailed methodology to execute the project. Individual projects were based on journal review, which is aimed to help students relate the course materials to current scientific and industrial applications. Students were asked to find recently published journal papers based on their field of interest and related to the course materials from the recommended list of nanotechnology journals. They were also asked to submit a review of the article and presentation. In the review, students described the type of the nanomaterials, synthesis and characterization techniques, and applications described in the selected research.

For the group project, teams of 3-4 students were formed. The main goal was to conduct an extensive literature search (including patents) to understand the selected topic, and brainstorm together to come up with a new idea for nanotechnology application or an advancement for an existing technology. Student teams prepared a report of about 10 pages summarizing the literature and describing what new ways nanotechnology could be used in our daily lives or an industrial application.

General Chemistry (CHEM 111) and Electricity and Magnetism (PHYS 204B) are determined as prerequisites courses for the Nanoscale Science and Engineering course. Table 1 represents the lecture topics of Nanoscale Science and Engineering course that were covered during the seventeen-week semester. When the characterization techniques were covered, students had a chance to observe how to do morphological and structural characterization of silica nanoparticles and carbon nanotubes using the X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS), Fourier-Transform Infrared Spectroscopy (FTIR).

End of the semester, students were expected to accomplish the following outcomes:

1. Have an understanding and knowledge of nanoscience and engineering principles and applications,
2. Gain the ability to critically read journal papers and propose potential projects.
3. An ability to work in nano related research projects and industries

These outcomes were assessed by a survey and student learning evaluations, which gave information on how to improve teaching effectiveness and improve course design and curriculum to better prepare students for the nanotechnology and engineering field.

2.2.Engineering Elective Courses

Undergraduate Mechanical and Mechatronic Engineering students in CSU Chico, in addition to the department elective courses, can take elective courses from Civil Engineering, Electrical and Computer Engineering, and Sustainable Manufacturing programs (Table 2). Students also can take approved upper division CHEM, MATH, and PHYS courses, not listed here, as an elective courses.

Table 3 represents the elective courses and the number of Mechanical and Mechatronic Engineering students that were enrolled for each class since 2011, which give an idea about the student's interest in MECH and MECA elective courses. Each semester one technical elective course has been opened in the Mechanical and Mechatronic Engineering Department from Fall 2011 to Spring 2018. In Spring 2018, Spring 2019, and Spring 2020, two elective courses were opened.

Table 2. Approved technical elective courses that CSU, Chico offers for undergraduate Mechanical and Mechatronic Engineering students.

Course code	Course title
CIVL 302	Engineering Sustainability and Engineering Analysis
CIVL 313	Structural Mechanics
CIVL 411	Soil Mechanics and Foundations
CIVL 431	Environmental Engineering
CIVL 461	Water Resources Engineering
CIVL 567	Pipeline Hydraulics and Design
CIVL 592	Construction Management
EECE 311	Linear Circuits II
EECE 375	Fields and Waves
EECE 450	Optics
EECE 481	Electromechanical Conversion
EECE481	Electromechanical Conversion
MECA 470	Robotics Engineering
MECA 486	Motion and Machine Automation
MECH 389	Industrial Internship
MECH 408	Modeling and Simulation
MECH 410	Advanced Materials Science and Engineering
MECH 424	Mechanical Vibrations
MECH 430	Nanoscale Science and Engineering
MECH 433	Solar Energy Engineering
MECH 435	Low Speed Aerodynamics
MECH 499	H Honors Project
MECH/MECA 398	Special Topics
MECH/MECA 399	Special Problems
MECH/MECA 498	Special Topic
MECH/MECA 499	Special Problems
SMFG 347	Polymer Composites
SMFG 451	Quality Management
SMFG 458	Project Management
SMFG 477	Semiconductor Manufacturing

The number of students enrolled for the elective courses was in the range of 13 - 49 students. Most of the undergraduate students were interested in Mechanical Vibrations, Low Speed Aerodynamics, and Solar Energy Engineering. In Fall 2019, 22 students were enrolled for

Nanoscale Science and Engineering course, which was an impressive turnout for a course offered for the first time.

Table 3. CSU Chico Mechanical and Mechatronic Engineering elective courses and enrollment. This list demonstrates the popularity of the newly offered Nanoscale Science and Engineering course compared to the traditional Mechanical and Mechatronic Engineering courses.

Semester/Year	Enrollment	Course title
Fall 2011	24	MECH 436 – Air Pollution Control
Spring 2012	14	MECH 424 – Mechanical Vibrations
Spring 2013	16	MECH 408 – Modeling and Simulation
Fall 2013	13	MECH 435 – Low Speed Aerodynamics
Spring 2014	27	MECH 410 – Advanced Materials Science and Engineering
Fall 2014	26	MECH 408 – Modeling and Simulation
Spring 2015	30	MECH 433 – Solar Energy Engineering
Fall 2015	0	MECH 436 – Air Pollution Control (Canceled)
Spring 2016	26	MECH 424 – Mechanical Vibrations
Fall 2016	3	MECH 498 – Special Topics
Spring 2017	30	MECH 433 – Solar Energy Engineering
Fall 2017	26	MECH 408 – Modeling and Simulation
Spring 2018	44	MECH 435 – Low Speed Aerodynamics
Spring 2018	21	MECH 410 – Advanced Materials Science and Engineering
Fall 2018	49	MECH 424 – Mechanical Vibrations
Spring 2019	28	MECA 470 – Robotics Engineering
Spring 2019	21	SMFG 477 – Semiconductor Manufacturing
Fall 2019	22	MECH 430 – Nanoscale Science and Engineering
Spring 2020	24	MECH 408 – Modeling and Simulation
Spring 2020	19	SMFG 347 – Sustainable Polymer Composites

2.3.Nanotechnology Survey

The nanotechnology-related knowledge of students and the impact of nanotechnology on students' interest and awareness were evaluated using the Nanotechnology Survey. Table 4 shows the covered areas in the Nanotechnology Survey. The survey consists of fifteen questions as listed below analyzing the students' engagement in three categories: Nanotechnology Awareness, Motivation, and Retention. The survey was given to the students at the beginning of the semester and again at the end of the semester to monitor the effect of the course. Students were not aware of the categories and questions were not given in a categorical order. The Awareness questions aimed to reveal students' general knowledge about the basics of nanotechnology. Motivation questions demonstrated the interest of students in furthering their knowledge on the subject after the course. Retention questions probed students' interest in staying in the nano field in the future. Students were asked to respond to each question using a 5-level Likert Scale, that is, (1) the strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree. The last two questions of the survey allowed students to express their comments freehand on the nanotechnology and the future of the course. The survey results from the beginning and at the end of the semester were compared using a t-test at a 95% confidence level.

Table 4. Survey questions and categories (A: Awareness, M: Motivation, R: Retention).

Questions	Category
1. I know how small nanoscale is compared to human hair.	A
2. I can name a technology/device using nanotechnology in my daily life.	A
3. I plan to seek for a nanotechnology related engineering position when I graduate.	R
4. I plan to continue my advanced degree education in the nanotechnology field when I graduate.	R
5. I plan to seek for nanotechnology internship programs in the industry or research lab.	R
6. If there were a nanotechnology seminar in Chico, I would attend it.	M
7. I know at least one way that nanoscaled materials or devices are produced.	A
8. Nanotechnology increases manufacturing costs because it is expensive technology.	A
9. Nanomaterials are too small to be effectively applied in engineering	A
10. I plan to read nanotechnology related journal, book or magazine news	M
11. I would give a presentation related to nanotechnology to an audience I perceived as having more experience with nanotechnology than I	M
12. I would like to visit an industry or business that specializes in nanotechnology.	M
13. Nanotechnology is important for the society.	A
14. How do you think nanotechnology contributes to engineering?	
15. Which application(s) of nanotechnology interests you the most?	

3. RESULTS

The mean and standard deviations of students' survey scores were calculated and showed in Table 5 and Figure 1. While an improvement trend could be seen in the majority of the survey questions toward the end of the semester, statistical analysis showed that questions 1, 2, 6, and 7 were significantly scored higher at the end of the semester compared to the beginning of the semester ($P<0.05$). When scores were pooled by the three major categories, there were an improvement trend in all categories (Figure 2). Table 6 represents students' interests in different nanotechnology applications.

Table 5. Mean and standard deviations of scores for each survey question given to the students at the beginning and end of the semester.

	Beginning of the semester		**End of the semester**	
Questions	**Mean**	**SD**	**Mean**	**SD**
1	3.85	0.75	4.40	0.68
2	4.40	0.68	4.20	0.83
3	3.21	1.03	3.50	0.83
4	2.85	1.14	3.26	1.05
5	3.45	1.05	3.55	0.89
6	3.75	0.85	4.30	0.73
7	2.70	0.98	4.55	0.60
8	3.75	0.97	3.84	0.90
9	1.70	0.98	1.55	1.05
10	3.80	0.83	3.70	0.66
11	2.95	1.00	3.40	0.68
12	4.40	0.68	4.35	0.67
13	4.35	0.93	4.55	0.60

Table 6. Students' interests in applications of nanotechnology by field.

Nanotechnology Application	**Beginning of the Semester %**	**End of Semester %**
Medical Devices	18	36
Robotics	4	9
Biomedical	18	18
Automotive	5	5
Aerospace	9	9
Environmental	5	5
Electronics	32	23
Energy Storage Devices	5	32
NEMS/MEMS	-	14
Sensors	-	14

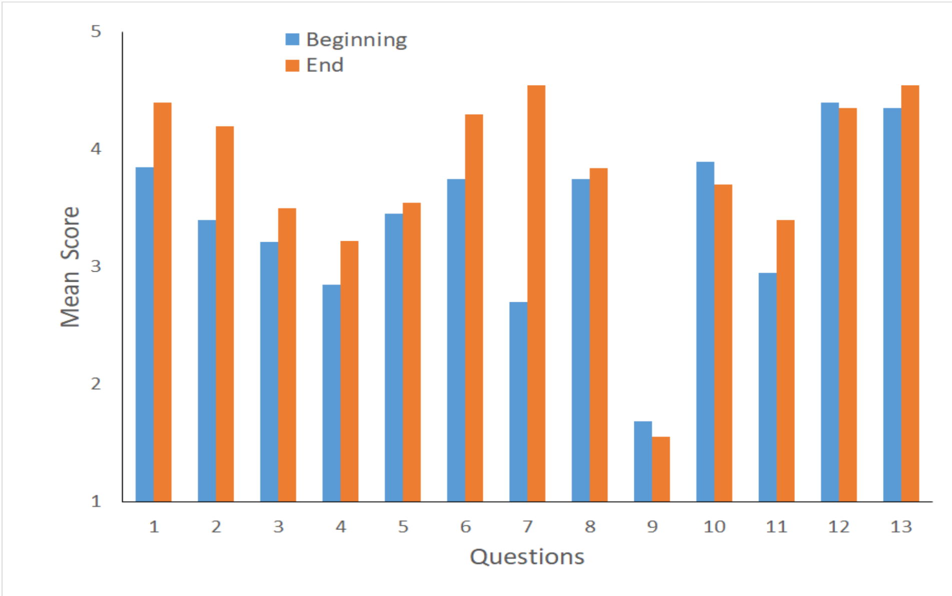

Figure 1. Mean scores for survey questions given at the beginning and end of the semester. All scores showed trend of increase at the end of the semester. Differences were statistically significant in questions 1, 2, 6, and 7 ($p<0.05$).

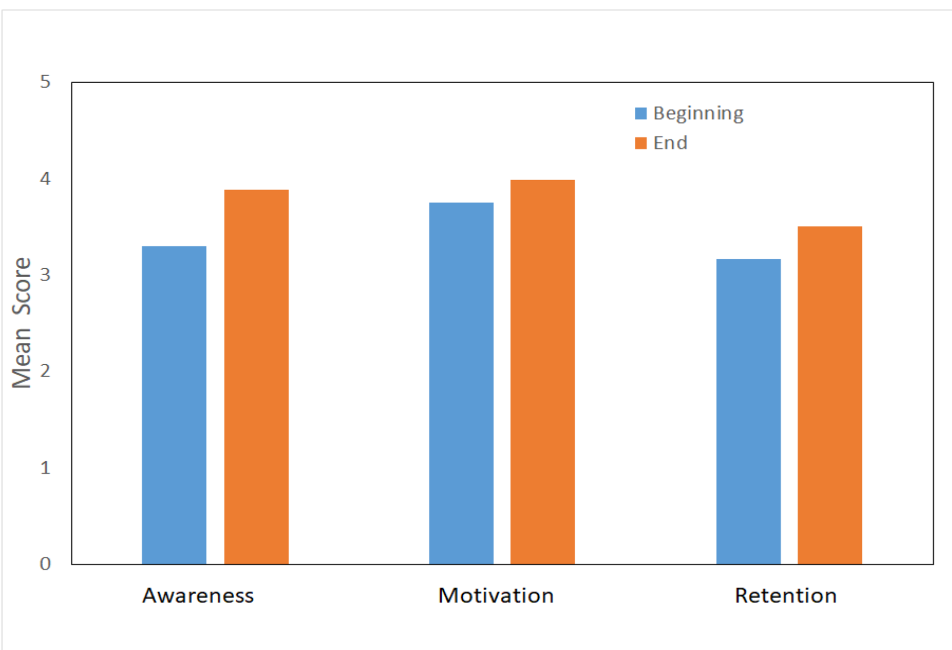

Figure 2. Mean scores for survey questions categorized in Awareness, Motivation, and Retention. There were increase in scores at the end of the semester compared to the beginning of the semester.

4. DISCUSSION

As the nanotechnology progresses and penetrates into every field of engineering, its integration into undergraduate engineering curriculum becomes inevitable. To address this need, a Nanoscale Engineering and Science course has been designed and integrated into Mechanical and Mechatronic Engineering curriculum at the California State University, Chico as an elective course for the first time in Fall 2019 semester. This report describes the course design and its impact on student perspective on nanotechology. A survey given to the students at the beginning of the semester and end of the semester showed that students' Awareness, Motivation, and Retention increased through this course.

The Awareness scores showed that students were able to better understand how nanotechnology was involved in their lives. During the course, the instructor made sure to include examples of nanotechnology used in daily life products. The final projects where students presented their ideas of nanotechnology products also seemed to help students realize the variety of applications of nanotechnology in our lives. The Motivation scores probed students' interest in nanotechnology topics and motivation towards increasing their knowledge in this field. The Retention scores demonstrated students' interest in staying in the nanotechnology field in the future through engineering career or graduate school. Students also indicated what fields of application of nanotechnology they are interested in the most. Results showed that emphasis on biomedical, electronic, and energy applications are most preferred.

The increase in the survey scores show that this course was successful in attracting students' attention to nano-related field and enthusiasm to learn more about it. The instructor observed that some students expressed interest in taking a position in the research projects in her Nanotechnology laboratory.

Moreover, the traditional student in-class evaluations of the teaching and course had interesting and encouraging comments. Some the student comments were as follows:

> *"It has really opened my eyes to seeing my major (Mechanical and Mechatronics) in a new light, with more options, and interest."*

> *"I liked being able to see and use the machines we talked about."*

"Exposing us to how the topics fit into nature is a big plus. Perfect way to hook students."

"I would like to have spent more time on the applications of nanomaterials and possibly career paths involving class."

"The class was kept very engaging."

"More lab times to practice."

"Overall process of production of nanomaterials interest me. If a job came up with that, I would take it."

4. CONCLUSIONS

The majority of the students in CSU Chico are first generation college student in their families and come from minority communities. This course was their first opportunity to get exposed to the fundamentals and various applications of nanoscale engineering and science. The impact of a single course on nanotechnology on students' perspective and career goals is clearly remarkable and great success. These results confirmed that the learning objectives of this course are successfully met. Based on students' feedback, laboratory sections will be added in the future semesters to improve the course.

REFERENCES

[1] L. Jia, "Global Governmental Investment in Nanotechnologies," *Curr Nanosci,* vol. 1, no. 3, pp. 263-266, Nov 1 2005.

[2] A. Keiper, "The Nanotechnology Revolution," *The New Atlantis (A Journal of Technology & Society),* vol. 2, no. Summer, pp. 17-34, 2003.

[3] (2020, 4/10/2020). *The National Tehcnology Initiative (Nano.gov)*. Available: https://www.nano.gov/about-nni/what/funding

[4] R. Shabani, L. Massi, L. Zhai, S. Seal, and H. J. Cho, "Classroom modules for nanotechnology undergraduate education: development, implementation and evaluation," *European Journal of Engineering Education,* vol. 36, no. 2, pp. 199-210, 2011/05/01 2011.

[5] M. J. Klopfstein, C. Lisa, A. L. Don, J. Xiaoliang, and R. P. Prabhakar, "Assessing the Effectiveness of a Nanotechnology Educational Module Using the "Nanotechnology Awareness Instrument"," New Orleans, Louisiana, 2016/06/26, 2016. Available: https://peer.asee.org/26308

[6] K. Dhananjay, M. P. Devdas, M.-D. Kwadwo, L. Robin Guill, F. Mainul Kader, and L. Courtney, "Impacting Undergraduate Nanoscience and Nanoengineering Education at North Carolina

A&T State University," San Antonio, Texas, 2012/06/10, 2013. Available: https://peer.asee.org/21478

[7] K. Ali, "Nanotechnology Undergraduate Education Initiative," Vancouver, BC, 2011/06/26, 2011. Available: https://peer.asee.org/18895

[8] M. A. Dyehouse, H. A. Diefes-Dux, D. E. Bennett, and P. Imbrie, "Development of an instrument to measure undergraduates' nanotechnology awareness, exposure, motivation, and knowledge," *Journal of Science Education and Technology,* vol. 17, no. 5, pp. 500-510, 2008.

[9] K. Ahmed, E. Barbara, and M. John, "Examining The Impact Of Nanotechnologies For Science, Technology And Society (Sts) Students," Chicago, Illinois, 2006/06/18, 2006. Available: https://peer.asee.org/961

[10] M. C. Benita, K. Rohit, and K. Sang-Gook, "Development and Growth of an Undergraduate Micro/Nano Engineering Laboratory Course," San Antonio, Texas, 2012/06/10, 2012. Available: https://peer.asee.org/21200