2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #39614

Addressing the Sustainable Engineering Skills Gap through Engineering Curricula

Dr. Ashish D. Borgaonkar, New Jersey Institute of Technology

Dr. Ashish Borgaonkar works as Asst. Professor of Engineering Education at the New Jersey Institute of Technology's (NJIT) Newark College of Engineering (NCE) located in Newark, New Jersey. He has developed and taught several engineering courses primarily in first-year engineering, civil and environmental engineering, and general engineering. He has won several awards for excellence in instruction; most recently the Saul K. Fenster Award for Innovation in Engineering Education. His research focuses on increasing diversity in STEM education and the STEM workforce. He has received multiple grants to run workforce development training programs as well as undergraduate research experience programs to train underrepresented minority and first-generation students. He is the Founding Director of NJIT's Grand Challenges Scholars Program. He also has worked on several research projects, programs, and initiatives to help students bridge the gap between high school and college as well as to prepare students for the rigors of mathematics. He is also involved in various engineering education initiatives focusing on the integration of novel technologies into the engineering classroom, and excellence in instruction. His additional research interests include water, and wastewater treatment, civil engineering infrastructure, and transportation engineering.

Dr. Samuel C. Lieber, P.E., New Jersey Institute of Technology

Samuel C. Lieber, PhD, PE is an Assistant Professor of Advanced Manufacturing in the Engineering Technology Department and Mechanical and Industrial Engineering Department at the New Jersey Institute of Technology (NJIT). Dr. Lieberâ€™s applied research i

Dr. Mohsen Azizi, New Jersey Institute of Technology

Mohsen Azizi is an assistant professor in the School of Applied Engineering and Technology at New Jersey Institute of Technology (NJIT). He received the M.Sc. and Ph.D. degrees in electrical and computer engineering from Concordia University, Montreal, Canada, in 2005 and 2010, respectively. From 2010 to 2013, he was an R&D engineer at Aviya Tech Inc. and Pratt & Whitney Canada Inc., Longueuil, Canada, where he designed and developed control and fault diagnosis systems for jet engines. His research has been focused on decentralized control and fault diagnosis techniques in microgrids, renewable energy systems, mechatronics, and aerospace.

Addressing the Sustainable Engineering Skills Gap through Engineering Curricula

Abstract:

Sustainable Engineering has become a major focus to not only conserve energy and resources but also reduce the production costs of realized products. The concept of Sustainable Manufacturing encourages the manufacturing of products using processes that minimize the overall negative impact through the conservation of energy and resources. One of the challenges in Sustainable Manufacturing is that many currently available processes are not economically sound compared to other traditional processes. However, this dynamic is changing very rapidly. The other significant challenge is the shortage of skilled workers in this area. This pressing need has highlighted the clear Skills Gap in the workforce. This paper reviews Sustainable Engineering outlining the career options and learning objectives that need to be addressed. A case study-based discussion will be provided on how Mechatronics and Renewable Energy curricula could be used as potential options to address the multi-/interdisciplinary skills gap. These curricula could be applied at multiple levels of engineering education, including high school, 2-year programs, and higher education. Thus, they present a broad modular approach that could address several areas of need in the Sustainable Engineering field.

Keywords: Sustainable engineering, curriculum design, innovative teaching

Introduction:

In the next 30 years, the existing 8 billion people on the planet are predicted to grow by approximately 2 billion. Therefore, using natural resources to enable people to live harmoniously and sustainably will rise along with the population. However, for the earth to continue to supply us with the resources, one must cooperate with the environment to ensure adequate resources for us and subsequent generations. It is at this phase where that sustainable engineering becomes pertinent. Sustainable engineering is the process of developing or managing systems in such a way that they use energy and resources sustainably, at a rate that does not harm the natural environment or future generations' capacity to satisfy their requirements. There are several ways to define overall sustainability, but it is frequently seen to contain three key elements: sustainability in terms of the environment, the economy, and society [1].

Innumerable nations throughout the world are progressively striving for sustainable development. Consequently, industries, including engineering, manufacturing, and design, have adopted sustainability practices [2]. Particularly manufacturing industries are becoming ever more concerned with environmental issues as modern socio-economic systems depend heavily on them since it greatly impacts worldwide development and progress. This trend is anticipated to continue because of the increased demand for consumer products from a growing global population with rising living standards [3]. Hence they now consider the link between production processes and the environment a key consideration when making decisions [2]. And implementing sustainable manufacturing techniques inside a company may help it become more resource-efficient, decrease waste, and use less energy [4]. However, a dearth of qualified people in this field is preventing enterprises from adopting sustainable manufacturing.

It appears that sustainable manufacturing is growing swiftly, and this sector will need more trained personnel in the future. Furthermore, to respond to the requirements and difficulties of changing environments and societies, engineering practice, and education must be regularly altered to take into account technological and methodological advancements [5].

Literature Review:

Sustainable engineering education in the United States has grown in recent years as the demand for professionals with expertise in designing and implementing sustainable solutions has increased. The United Nations has devised a list of 17 sustainable goals which must be accomplished by 2030. These objectives address social issues like poverty, hunger, health, education, gender equality, reducing inequality, and safe cities; resource issues like water, energy, sustainable production and consumption, and the marine environment; resilience issues like climate change and sustainable ecosystems; and international cooperation for sustainable development [6]. Professional organizations that support sustainable engineering education and offer information and networking opportunities for industry professionals include the American Society of Mechanical Engineers (ASME) and the Institute of Electrical and Electronics Engineers (IEEE). In addition, many universities offer undergraduate and graduate programs in sustainable engineering, environmental engineering, and related fields. These programs often focus on interdisciplinary approaches and provide students with a comprehensive education in sustainable engineering and design principles. The sustainable engineering design curriculum is a thorough educational program that prepares learners for sustainable engineering and design principles. It usually covers a variety of subjects, such as:

1. Environmental science and sustainability: understanding sustainability concepts and how human activity affects the environment.
2. Sustainable design methods: designing goods, systems, and services following sustainable design principles.
3. Renewable energy systems: Designing and setting up renewable energy systems, such as hydropower, solar, and wind power.
4. Energy efficiency: designing and implementing energy-efficient architecture, products, and systems.
5. Water and waste management: creating and implementing environmentally friendly water and waste management techniques.
6. Lifecycle analysis: examining a product or system's environmental impact across its entire lifecycle.
7. Climate change and adaptation: recognizing the effects of climate change and developing measures to counteract them.

The sustainability learning module is introduced to students in their first year at many prominent universities. The objective is to study sustainability methodically and from an engineering standpoint. In addition, use techniques to compare the sustainability performance of various alternative solutions. The module content comprises sustainable designs, performance indicators, strategies, etc.[7] . Sustainable manufacturing can be categorized into four; Responsive Product Strategy (RPS), Lean Practices (LP), Supply Chain Restructuring (SCR), and Sustainable Material and Design [8]. Considering the possible effects of environmental issues on a business's operations, financial performance, and reputation, as well as incorporating this knowledge into decision-making and planning processes, constitutes integrating environmental risk into corporate strategy. This may involve recognizing and evaluating environmental hazards and incorporating them into company planning and risk management techniques. Examples of such risks include the consequences of climate change, resource depletion, and legislation. To lessen exposure to environmental risks and enhance company sustainability, it may also entail implementing sustainability strategies, such as cutting emissions and waste, conserving resources, and marketing eco-friendly goods and services. By incorporating environmental risk into corporate strategy, businesses can reduce adverse effects, boost their competitiveness, improve their reputation, and help accomplish sustainable development goals. Some best practices include redesigning products and processes to be more environmentally friendly and pushing suppliers to practice pollution prevention [9]. For example, the carpet industry consumed water and energy in the past years. Now, carpet manufacturers are taking measures to lessen environmental impacts, which is currently the most environmentally conscious industry in the textile industry. The main conceptual issues with sustainable engineering may arise when sustainability is viewed as an objective function compared to a guiding myth [10].

Scope of Sustainable Engineering Education

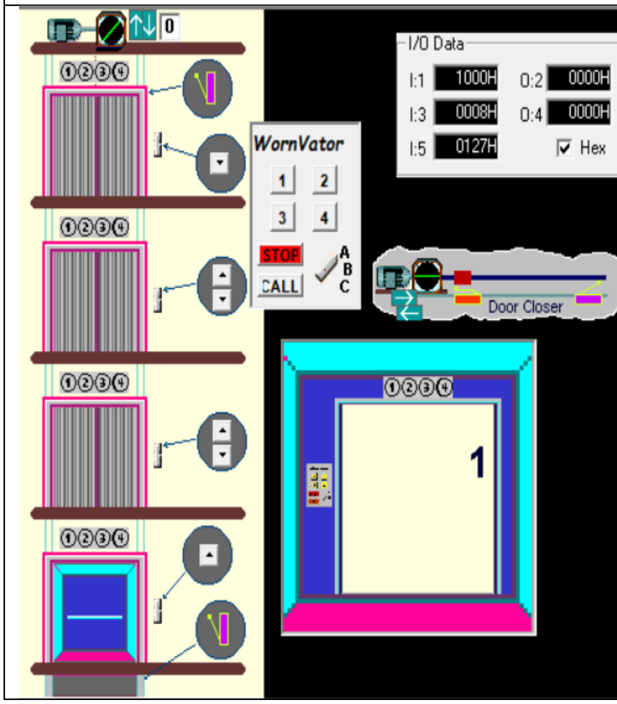
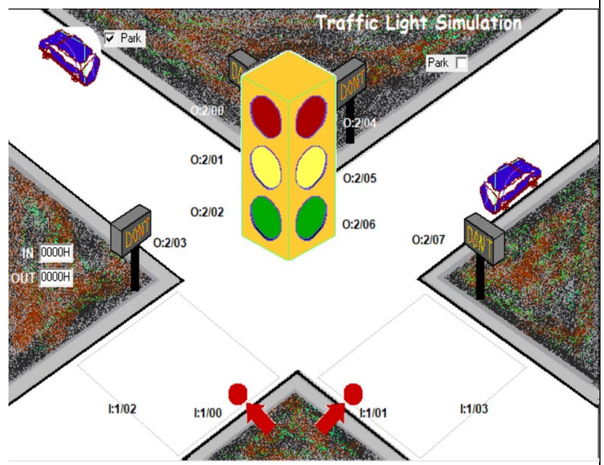
This work focuses on implementing Sustainable Engineering education in two technical fields in the School of Applied Engineering and Technology (SAET) at the New Jersey Institute of Technology (NJIT) located in Newark, NJ, USA.

- ***Mechatronic*** education toward process optimization and automation.
- ***Renewable Energy*** education towards integration in traditional powering grids.

These technical areas also allow one to discuss two delivery methods that use software and a physical setup. Our Renewable Energy courses best emphasize the application of physical systems, while our Mechatronic courses best show the use of simulation software for Sustainable Engineering Education.

Mechatronic Education. Resources for SAET’s mechatronic laboratory were previously characterized as physical training systems and software enabling process simulation [11]. Regarding the sustainable engineering learning objectives, both choices provide excellent resources. However, the fundamental benefit of the software-based method is that it is both affordable and accessible to students at home and in the lab for ongoing practice. This allows study in event sequencing, a key area of automation. Therefore, the main topic of this section is the benefit of using the LogixPro Allen Bradley RSLogix Simulator software (LogixPro) for sustainable engineering education.

LogixPro: Multiple alternatives are available in LogixPro to virtually test out automated procedures. Figure 1 illustrates two distinct automation instances.

Figure 1. Simulators on LogixPro	
Elevator Simulator	**Traffic Simulator**
	

Typically, the simulations of industrial processes provide students the opportunity to experiment with input (push buttons and sensors) and output (such as motors) configurations to examine the influence on sustainability. Sustainability metrics include:

- Exploring ways to reduce the number of parts required in a mechatronic setup by:
    - Optimizing hardware selected using control software.
    - Software approaches to replace hardware (e.g., software timers).

The simulations enable the students to iterate by providing them with instant feedback on the results of their decisions. The simulator also depicts process failures that illustrate the balance between mechatronic optimization and process performance. As a result, the simulation offers a platform for validating the automated process and iterating on sustainable choices. Several modules that may be utilized to promote sustainable education are listed in Table 1 below.

Table 1. LogixPro Simulator Options for Sustainable Engineering Education.

Simulation Title	Overview
Utilizing Traffic Simulator	Students write a documented program for efficient traffic flow. This highlights how controls can simplify an automated setup and control the traffic to minimize vehicle idling times.

Utilizing Bottle Line Simulator	Students write a documented program for an automatic stacking process. Different methods can be explored to optimize this process of conveyors used in tandem
Utilizing Batch Simulator	Students write a documented program to trigger events for a batch-mixing process. Students can explore the optimization of a Thermal Fluid process and the results of their selections.
Elevator Simulator	Students write a documented program for efficient passenger pickup with an elevator. This highlights how controls can optimize an elevator's capacity while reducing the passengers' waiting time.

The simulation software allows a range of real-world scenarios to be explored.

***Renewable Energy Education*.**

NJIT has launched new courses on installing and troubleshooting Solar PV systems in partnership with Morris County Community College. To aid with the training of the highly sought-after renewable energy workforce, a new lab was constructed employing cutting-edge technology. A summary of this study was presented at an ASEE conference in the past [13].

This initiative emphasized solar photovoltaic technology by developing a cutting-edge lab and curriculum to provide engineering technology students with the practical skills needed to bridge the skills gap between market demand and labor supply and fill relevant industrial jobs.

To design the laboratory experiments for the new courses, the following Amatrol Inc. items were purchased and used in the new laboratories: "Solar Concepts Learning System (950-SC1)" multimedia software, "Solar PV Installation Learning System (950-SPF1)" demonstrated in Figure 2, and "Solar PV Troubleshooting Learning System (950-SPT1)" demonstrated in Figure 3.

Fig 2. Solar PV Installation Learning Module [12]

Fig 3. Solar PV Troubleshooting [12].

NJIT's new course, "Solar PV Planning and Installation," involves 2 hours in class and 2 hours of lab time, and it carries three credit hours. Circuits II (ECET 202), a prerequisite course, is available to sophomores and above. The course flow diagram is shown in Figure 4. This course's discussion of solar PV systems includes an introduction to renewable energy and PV systems, solar thermal systems, solar radiation, sun path characteristics, solar panel orientation, wire selection and sizing, ground and lightning protection, installation, startup, commissioning, and troubleshooting. In addition, it covers a variety of practical difficulties for commercial and residential applications, such as identifying and analyzing sites for array locations; developing and implementing a site layout; calculating PV circuit voltages and currents; selecting, cutting, stripping, and connecting wire; and installing components in a PV system.

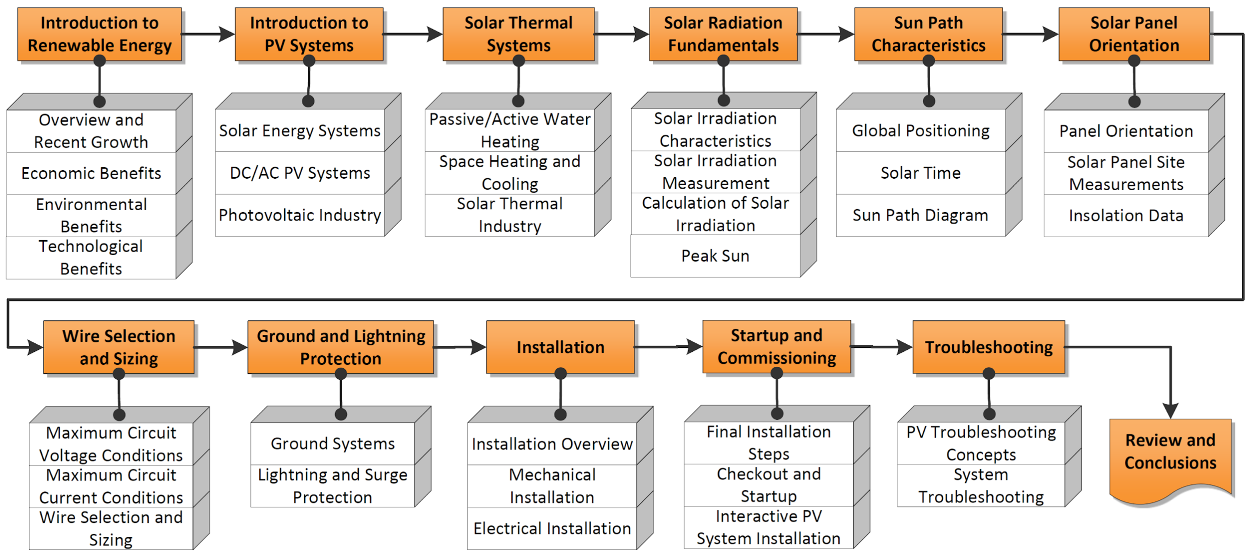


Fig 4. Solar PV installation and troubleshooting course flow diagram.

The new "Solar & Alternative Energy Systems" course at our partner community college is similar to the one at our university (3 credits, Class 2 hours, Lab 2 hours). Still, because the two-year program's emphasis is on careers as technicians, it was decided to make the course at the community college more about troubleshooting. Circuit Analysis DC/AC is a prerequisite course. (ELT 100). The community college has constructed various solar PV arrays on its campus, which produce close to 400 kilowatts of electricity (or around 45% of its yearly energy requirements). These PV arrays were used to create hands-on experiments for the new courses, giving students from our institute and the community college a chance to evaluate actual residential PV systems and make recommendations for boosting their electric power output in accordance with the theories they are learning in the new courses.

This new course was developed in close collaboration with an industrial advisory committee, including industrial partners from the power and renewable energy industries. They examined every content created for the new course and laboratory and offered suggestions for improvement. The proposed changes and modifications were strictly adhered to and put into practice. Furthermore, the students' end-of-semester course ratings revealed a high degree of satisfaction with several components of the new course, including but not limited to "course material quality" and "course educational value."

Benefits for students:

Nowadays many businesses have created ecological alternatives in response to climate change, pollution-related problems, and energy prices. They seek individuals with knowledge of and experience in sustainable engineering. Students can improve their employability and raise their chances of landing a job in this expanding industry by finishing a sustainable engineering curriculum. Integration of several academic disciplines, including environmental science, social science, and economics, is necessary for sustainable engineering. Students are exposed to interdisciplinary learning through the inclusion of sustainable engineering in the curriculum, which can broaden their perspectives and aid in the development of a more all-encompassing approach to problem-solving. The teaching of sustainable engineering to students aids in developing in them a sense of environmental responsibility. They learn ways to reduce their harmful effects on the environment and become more conscious of how their behaviors affect the environment.

Conclusion:

Sustainable Engineering is key to bringing back manufacturing to the US, and this will increase the demand for trained individuals on an unprecedented scale. Even though sustainable engineering-focused degree programs are available in a few places in the US, it is important to embrace this concept and adopt it at various scales throughout the engineering curriculum, especially in manufacturing and related majors. The scope of this paper was to present a few methods that have successfully been implemented at our institution. The views presented here are a mix of stand-alone and collaborative modules across partner institutions. They can easily be adopted in similar courses with careful planning. These modules align the learning objectives to career pathways available to engineering and technology graduates. The options include economical simulation software providing options for event sequencing, as well as more costly physical laboratory systems. The range of economic options presented allow these curricula to be applied at multiple levels of engineering education, including high school, 2-year programs, and higher education. Thus, they present a broad modular approach that could address several areas of need in the Sustainable Engineering field. Future work at our institution involves evaluating the direct effects of implementing these education tools. This multidisciplinary study would need to be conducted across several departments where these methods have been implemented.

References

1. Rosen, M.A., *Engineering sustainability: A technical approach to sustainability.* Sustainability, 2012. **4**(9): p. 2270-2292.
2. Rosen, M.A. and H.A. Kishawy, *Sustainable manufacturing and design: Concepts, practices and needs.* Sustainability, 2012. **4**(2): p. 154-174.
3. Haapala, K.R., et al., *A review of engineering research in sustainable manufacturing.* Journal of manufacturing science and engineering, 2013. **135**(4).
4. King, A.A. and M.J. Lenox, *Lean and green? An empirical examination of the relationship between lean production and environmental performance.* Production and operations management, 2001. **10**(3): p. 244-256.
5. Halbe, J., J. Adamowski, and C. Pahl-Wostl, *The role of paradigms in engineering practice and education for sustainable development.* Journal of Cleaner Production, 2015. **106**: p. 272-282.
6. Thorpe, D., *Meeting the challenges of engineering a sustainable future.* GEOMATE Journal, 2018. **14**(43): p. 8-18.
7. Esparragoza, I.E., J.A. Mesa, and H.E. Maury. *Developing Assessment Tools for Sustainability Learning in Engineering Education*. in *2017 7th World Engineering Education Forum (WEEF)*. 2017. IEEE.
8. Nordin, N., H. Ashari, and M.F. Rajemi, *A case study of sustainable manufacturing practices.* Journal of Advanced Management Science, 2014. **2**(1): p. 12-16.
9. Rusinko, C., *Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes.* IEEE transactions on engineering management, 2007. **54**(3): p. 445-454.
10. Allenby, B., et al., *Sustainable engineering education in the United States.* Sustainability Science, 2009. **4**: p. 7-15.
11. Lieber, S. C., & Borgaonkar, A. D. (2020, November), *Focusing on the Silver Lining: How COVID-19 Pandemic is Influencing the Pedagogy of Mechatronic Course Delivery to Support the Industrial Role of a Mechanical Engineering Technologist,* 2020, Fall ASEE Mid-Atlantic Section Meeting, Virtual (hosted by Stevens Institute of Technology). https://peer.asee.org/36047
12. Amatrol Inc., Jeffersonville, Indiana. "[website] www.amatrol.com ".
13. Mohsen Azizi, Venancio Fuentes 2022a. "Design and Development of a New Course and Laboratory: Solar PV Installation and Troubleshooting." ASEE Conference for Industry and Education Collaboration (CIEC), Tempe, Arizona.