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Board #442: Data-driven Approach to Problem Solving in Renewable Energy and Engineering Education

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WIP: Data-driven approach to Problem Solving in Renewable Energy and Engineering Education

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Abstract
Courses based on experiential learning provide an excellent avenue to promote problem-solving and collaborative skills among the students in STEM. However, the current engineering curriculum does not have sufficient project-based learning emphasizing collaborative research on renewable energy to support the government's goal of Net Zero emissions by 2050. So, this work-in-progress presents the results from our recent implementation of project-based learning assignments to existing courses to model and analyze renewable energy systems while introducing machine learning methods. We used assignments and selected projects to introduce concepts related to reducing GHG emissions through renewable energy sources, improvement in efficiency, or novel technologies. The courses included modules covering two supervised machine learning algorithms, video lectures, and tutorials for analyzing and evaluating data sets of each technology using computational tools. Finally, indirect and direct assessments were carried out, including pre- and post-course qualitative surveys completed by students to assess the impact of the modules and course. Based on the results from the current work, future implementation will aim to (1) expand and implement additional machine learning instructional and training modules for sustainability projects using experiential learning, (2) promote a data-driven approach to solving engineering problems for complex problems in science and engineering, and (3) train future leaders on topics related to sustainability. These modules are to enable students to acquire the relevant knowledge and skills for data-driven modeling.

1. Introduction

The world is gradually acknowledging the value of transitioning from conventional fossil fuel driven energy to renewable energy sources. This has been brought up as a key point at the COP28 where there is a push to the end of fossil fuels dependence [1]. Recently, However, to realize the full potential of renewable energy needs addressing complex challenges such as intermittency, grid integration, and resource optimization. In this context, data driven modeling and analysis emerges as a powerful tool for analyzing large datasets and coming up with actionable insights. By harnessing data-driven approaches, we can enhance efficiency, reliability, and sustainability in the renewable energy sector.

Before delving into data-driven modeling solutions, it is critical to understand the background and current status of renewable energy technologies. We will explore the inherent variability and uncertainty associated with renewable resources, emphasizing the need for innovative problem-solving methods. processing and managing diverse datasets of renewable energy systems that generate data from various sources—weather patterns, energy consumption, and grid operations [2, 3]. Data-driven techniques enable us to handle this complexity effectively. Machine learning (ML) Algorithms can be learned from historical data, predict energy generation, optimize grid operations, and enhance overall system performance. Furthermore, time-series analysis can be carried out to understand dynamic behavioral patterns that is crucial for managing optimizing efficiency and resource utilization. Finally, optimization algorithms help us make informed decisions, allocate resources efficiently, and minimize waste and losses in energy [3].

Renewable energy and sustainability are critical topics in engineering. We live in an age of environmental awareness, and alternative energy education is present in most of our daily conversations in engineering, technology, and science education. Renewable energy today provides about 9% of the world's energy and 8 to 10% of the U.S. needs [4]. However, in many parts of the world, these percentages are increasing significantly. Based on current data on global warming, as well as the current U.S. dependence on overseas oil, there is an interest and urgency in utilizing alternative energy sources [5].

In order to prepare students for their future careers, real-world training is imperative for their education. University campuses in the United States are taking important steps to establish alternative energy research and education [5]. For example, undergraduate engineering and engineering technology programs are now including laboratory-based curriculum in alternative energy [5]. Hands-on laboratory experiments using educational training units offer enhanced learning experiences. These units provide a real-time display of key system properties as well as surrounding conditions through a data acquisition system. The majority of alternative energy educational training units are built and sold by companies that offer custom-made systems according to the customers' needs; this increases the cost of the training units. Alternative energy teaching tools help students to fully comprehend complex concepts with interactive educational training equipment and are very important for the hands-on laboratory sections of energy education. Due to the high costs of educational training units, it has become a budget concern when purchasing training equipment for the laboratory sections of the courses. The costs of such equipment range from ten thousand to fifty thousand dollars per unit [5].

Undergraduate engineering or engineering technology curricula are facing a number of challenges, including a rapid growth in what is perceived by the technical community to be a necessary foundation of knowledge, the realization that our workforce must be able to operate in a diverse global society, and the recognition that the implementation of technology can have an enormous impact on the sustainability of our global resources. If the students are going to successfully function as professional engineers in the international corporate world of the 21st century, they must be equipped to be global engineers who are technically versatile (multi-disciplinary), able to solve problems from a systems-level perspective, effective communicators, function in diverse ethnic teams, and demonstrate social responsibility [6].

Accordingly, the undergraduate curricula must keep evolving to provide the proper learning environment for students to develop these characteristics. Due to the unprecedented growth of renewable energy technologies and in the interest of keeping students abreast of the current scientific and technological developments and trends, we believed that it was important and timely to develop an undergraduate course on renewable energy. There is also a well-documented demand and need for offering program study, courses, and training in the areas of renewable energy and power systems [6]. This course focuses on wind energy conversion, solar, and fuel cell systems, and the impacts of the intermittent of renewable energy on power systems. We also strongly believe that renewable energy topics must be included when it is appropriate into other courses in our program, especially as projects, an essential aspect of engineering education. The paper by Belu and Husanu discusses the importance of embedding renewable energy and sustainability into engineering technology curricula [7]. The paper highlights the growing demand for trained engineers and technicians in renewable energy and sustainability areas, and the need for innovative curricula, new courses, and laboratories to educate students to work in this rapidly developing industry. The paper proposes a problem-oriented and project-based learning approach to teach sustainability and alternative energy in today's engineering curriculum. The paper also discusses a series of projects included in senior project design, power electronics, and renewable energy courses, and the structure of these projects, outcomes, observations, lessons learned, and future improvements [7].

Similarly, due to the unprecedented growth of data-driven methods such as ML and in the interest of keeping students abreast of the current technological advancement and trends, it was important and timely to develop content related to ML. The paper by Zhang discusses the use of Excel as a tool to teach ML concepts to engineering and physics students [8]. The paper highlights the importance of ML in the fourth industrial revolution, where data becomes as important as energy and materials [8]. The paper also emphasizes the challenges of programming in learning ML and proposes a two-stage approach to learning ML: in the first stage, students concentrate on the concepts and methods of ML with very simple programming tools, and in the second stage, students practice with more advanced tools, such as Tensorflow. The paper describes how Excel was used to train simple neural networks in a one-credit introductory course on ML. The paper concludes that Excel is a good platform to introduce ML to students without extensive programming background [8]. Moreover, the paper by Mohaghegh discusses the contributions of Artificial Intelligence (AI) and ML to many engineering industries [9]. The paper highlights two classes of contributions: Class One, which involves minimizing or avoiding assumptions, interpretations, and simplifications in order to build highly realistic models of the physical phenomena, and Class Two, which involves minimizing the computational footprint of the numerical models such that they can act in a realistic and practical manner. The paper also emphasizes the importance of engineering domain expertise in the successful and realistic application of AI and ML in engineering disciplines [9]. The paper provides insights into the differences between modeling and solving engineering versus non-engineering related problems using AI and ML. It also discusses the importance of understanding the ethics of AI in engineering, expertise of AI, modeling physics using AI, and differences between AI and traditional statistics. Finally, a paper describes a software package based on neural network and expert system technology that emulates the interview and evaluation process to measure the intellectual development of engineering students [10].

This work-in-progress study sought to incorporate analysis of renewable energy and sustainability applications using ML techniques. There, the objectives of this work-in-progress study are:

1. Develop and implement a project-based learning course to model and analyze renewable energy systems using ML methods
2. Train students in various sustainability topics including lab-scale CO2 sequestration in deep saline aquifers and fuel cells
3. Offer the course in modules covering several supervised and unsupervised ML algorithms
4. Provide video lectures and tutorials for analysis and evaluation of data sets of each technology with computational tools for each ML model

This paper is organized into Section 2 that provides the course design and setup, Section 3 that provides the results from student surveys and grades, and finally, Section 4 that contains concluding remarks and future work.

2. Course design

2.1 Course structure

For the pilot study, we implemented the modules across four undergraduate senior-level classes and one graduate engineering class in the mechanical engineering department in Fall 2023. The mechanical engineering courses were taught at two different locations in a combined mode of instruction – simultaneously online synchronous to the rural location in Tyler and face-to-face in the urban location in Houston. These courses were selected for the pilot study as they focus on at least some aspects of energy generation, use, and efficiency. This approach would allow the student to choose intuitive projects that satisfy the course outcomes while introducing and implementing ML techniques and applications. The courses where we piloted the ML modules are summarized in Table 1.

Table 1: Summary of the Classes with EOP Implementation

Course Name	Course Number	Level*	Class Size
Introduction to Renewable Energy Systems	MENG 4349	UG	50
System Dynamics and Control	MENG 4312	UG	37
Process Control	MENG 5330	G	13

*UG: Undergraduate, G: Graduate

For each class, student groups, ranging from 2 to 5 students in each self-selected group, were formed to work on a project. For a completion grade, the first assignment by each student group was submitting the project's title and a brief abstract to be approved by the instructor. The students were instructed to choose projects based on their relevance to the respective courses (Table 1). The students were then instructed to submit a graded preliminary report on their selected topic to receive feedback. The instructor provided opportunities for discussion on the initial report and detailed feedback so that the student groups could prepare the final report. At the end of the semester, each group needed to submit recorded video presentations on the preapproved topics.

The survey was created and distributed by the instructor in Qualtrics, where the questions used a Likert scale for quantitative analysis while the comments were provided for qualitative analysis. Students were asked to rate the agreeability of their abilities after completing the project. The survey was distributed during the last week of classes in the Fall 2023 semester after being approved through the standard Institutional Review Board process (University IRB#FY2021-42).

2.2 Integration of Machine learning modules

Recorded lectures were dedicated to briefly introducing the students to the major aspects of the ML as well as two specific topics: artificial neural network and random forest. The application included fuel cell data modeling and analysis using MATLAB and carbon dioxide sequestration data modeling and analysis using Python as computational tools. The students completed an assignment where they are asked about each topic based on the lectures and to complete examples provided to apply what they learned. This was required for all 3 courses where all students had already taken Heat Transfer course and Calculus course to be able to enroll in their respective courses. Use of ML in an additional homework problem and in the course project was required for MENG 5330 students due to their existing background in undergraduate linear algebra, differential equations and control theory.

The incorporation of data analysis and modeling fills the gap and supplements the engineering curriculum by emphasizing ML techniques and associated computational tools. This data-driven approach in renewable energy and sustainability applications is expected to help prepare students to potentially make an impact in various relevant industry application such as Real-Time Forecasting of Renewable Energy Generation by Predicting energy output based on weather conditions and other factors and Predictive Maintenance for Renewable Energy Infrastructure by Ensuring optimal performance and longevity of renewable assets.

3. Results and Discussion

The post-completion survey for the course was completed by 65 out of 100 students across all the classes (Table 2). The highest fraction of completion (92%) was observed for MENG 5330. In contrast, only 62% of the students completed the survey for System Dynamics and Control (MENG 4312).

Table 2: Number of responses to survey for each class

Course Number	Class Size	Participation
MENG 4312	37	23 (62%)
MENG 4345	50	30 (60%)
MENG 5330	13	12 (92%)

Next, we evaluated the written responses about their experience with ML for all courses. Here are a couple of notable student comments: “I would say the use of ANN modeling and the challenge of modeling higher order systems certainly allows one to understand the complexity of a real-world process control scenario. This includes knowing what concepts to apply in certain situations, and at the very least, be able to be strongly grounded in fundamental concepts (MENG 5330)” and “Skills learned through the ML based module from this course include learning how to model and simulate a dynamic system in software such as Simulink. I also learned how to apply this knowledge to real-world concepts, especially in regard to designing a fuel cell (MENG 4312).” This shows these students had a positive understanding and appreciation of the importance of ML techniques and their implications in the future of industry.

The survey responses of MENG 5330 students were collected and analyzed as they were required to complete problems and a project involving ML. The responses were for relevant course outcomes that accounted for modeling and control of systems where they also incorporated ML as part of their learning experience. The responses are based on a Likert scale of 1 to 5 where 1 is strongly disagree and 5 is strongly agree. As it can be observed almost all students had relatively strong agreeability for modeling dynamic processes and utilizing computational tools to design and analyze control systems given ML techniques were incorporated in a couple of assignments.

Table 3.: Data of indirect assessment of student's ability to meet course learning outcomes relevant to machine learning

Assess your ability to accomplish the course learning outcomes.	**Average**	**Standard Deviation**	**High**	**Median**	**Low**	**Number of participants**
I am able to Analyze and model dynamic processes in time domain	4.42	0.64	5	4.50	3	12
I am able to Utilize computational tools to design and analyze different types of control systems.	4.42	0.64	5	4.50	3	12

Figure 1 shows the boxplot of the instructor's evaluation of the student ML assignments for each class. From the boxplot, each box in blue shows that the central mark in red indicates the median, while the bottom and top edges of the box indicate the 25^{th} and 75^{th} percentiles, respectively [11]. The whiskers in black extend to the most extreme data points not considered outliers, and the outliers are plotted individually using the '+' marker symbol in red [11]. Across all courses, the average grade distribution fell between A (90-100, excellent) and B (80 -89, good) due to the assignment being to gauge their basic understanding and application of examples related to ML. Most of them were able to complete the assignment successfully. A few students failed to submit the completed assignments.

Figure 2 shows the boxplot of the instructor's evaluation of the student projects and homework assignments for MENG 5330. The students did consistently well for a specific given problem from an assignment titled HW5 Empirical Modeling Problems by achieving a grade of A on average. However, the students did not perform as well for the project where they had to incorporate into a real-world problem. This seems to be challenging for them. However, there was one set of students who did an excellent job of developing a neural network-based control system for their HVAC system model. Overall, this grade distribution is promising for the pilot implementation, which we hope will improve with future iterations.

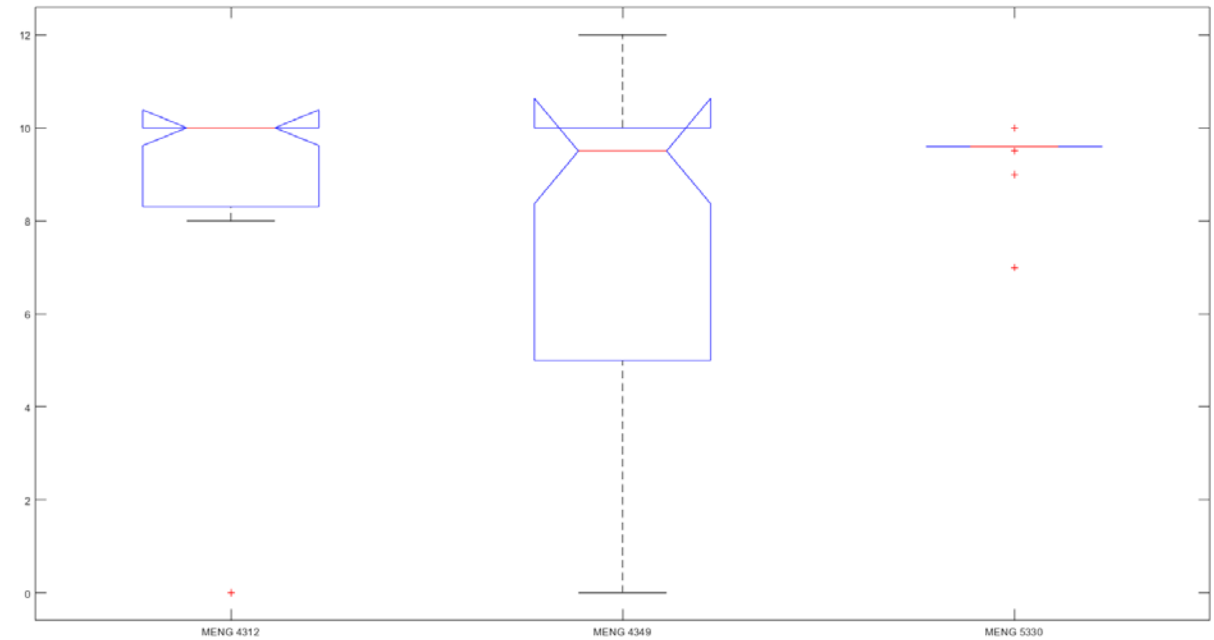

Figure 1. Instructor grade for ML related assignment across different classes.

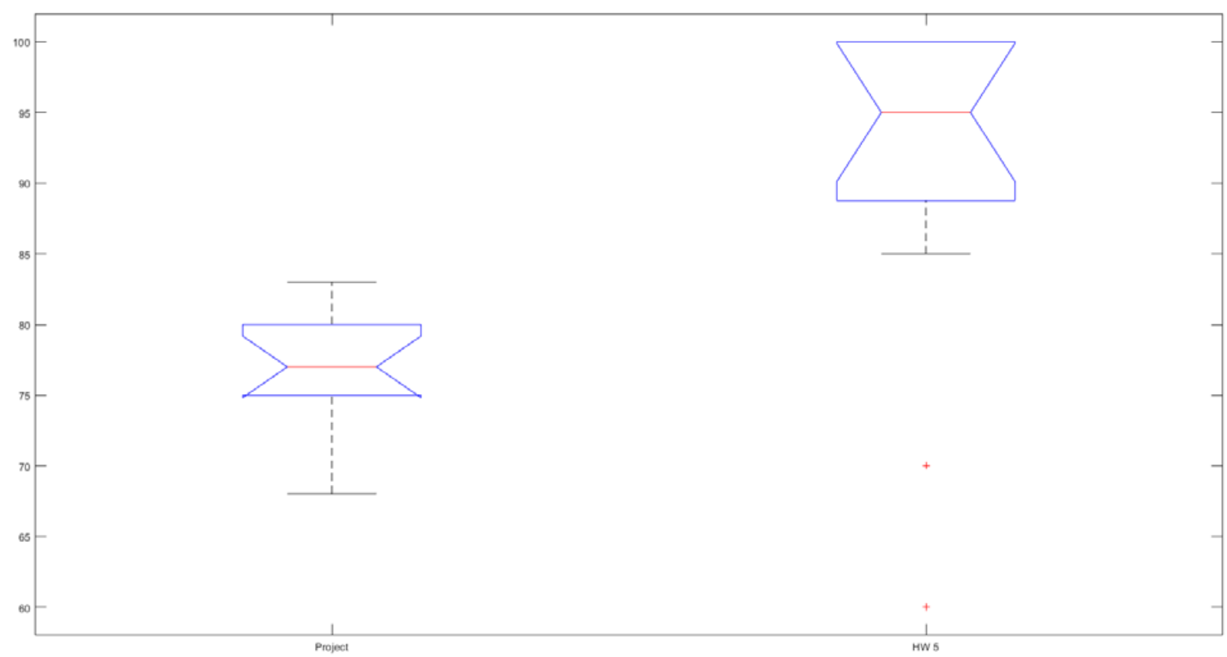

Figure 2. Instructor grade for ML incorporated assignments in MENG 5330.

4. Conclusion and Future Work

This paper presents results from a pilot study where data-driven approach involving ML was implemented in various mechanical engineering courses. The students were introduced to the different ML concepts including artificial neural network and random forest and were assigned an open-ended project related to the MENG 5330 while it was optional for the other courses. After completing the assignments and project, the students were asked to complete surveys to gauge their perception of the data-drive approach. Based on a few student written responses, it was observed that the ML based modules helped most students learn and apply this topic. Furthermore, based on the data analysis of the collected data, MENG 5330 students agreed that they were able to develop and analyze models and control systems including incorporation of ML techniques. This conclusion was also supported by the instructors' evaluation of student work, which showed a relatively good understanding of ML concepts. Future implementation would benefit from additional structured lectures on complex other data-driven approaches with additional mini assignments. This change will enhance student learning and retention compared to the self-study approach implemented in the current courses. The incorporation of data-driven approach in the MENG courses has the potential to be implemented in other engineering disciplines. Future studies will likely involve classes in chemical engineering. The findings from this study show that the implementation of data-driven approach in problem solving for engineering curricula can be used to better prepare future engineers in this data-driven world.

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References

[1] A. Mehta, "A COP where the world finally faced up to the need to wean itself off fossil fuels," Reuters, 15 December 2023. [Online]. Available: https://www.reuters.com/sustainability/climate-energy/cop-where-world-finally-faced-up-need-wean-itself-off-fossil-fuels-2023-12-15/. [Accessed 28 March 2024].

[2] R. Jalli, P. P. Kumar, R. S. Nuvvula, N. H. Haroon, B. Srinivasarao and A. Siddiqui, "Data Science Applications in Renewable Energy: Leveraging Big Data for Sustainable Solutions," in *12th International Conference on Renewable Energy Research and Applications (ICRERA)* , Oshawa, 2023.

[3] J. Liu, Z. Jiao, C. Chen, C. Duan and C. Pang, "Advanced data-driven methods and applications for smart power and energy systems," *Frontiers in Energy Research,* vol. 10, no. 1064305, 2023.

[4] D. Pimentel, M. Herz, M. Glickstein, M. Zimmerman and e. al., "Renewable energy: Current and potential issues," *Bioscience* , vol. 52, no. 12, pp. 1111-1120, 2002.

[5] F. Yildiz and K. Coogler, " Student-Built Renewable Energy Training Unit," in *ASEE Annual Conference & Exposition,* Louisville, 2010.

[6] R. Chiou, R. G. Belu, M. G. Mauk, M. E. Carr and T. B. Tseng, "Student Learning Experience from Renewable Energy Case Studies," in *ASEE Annual Conference & Exposition*, Atlanta, 2013.

[7] R. G. Belu and I. N. C. Husanu, "Embedding renewable energy and sustainability into the engineering technology curricula," in *ASEE Annual Conference & Exposition*, San Antonio, 2012 .

[8] Y. Zhang, "Teach Machine Learning with Excel," in *ASEE Virtual Annual Conference*, Virtual, 2020.

[9] S. Mohaghegh, "Engineering Application of Artificial Intelligence," in *ASEE North Central Section Conference*, Morgantown, 2023.

[10] M. J. Pavelich, B. Olds and R. Miller, "Measuring Engineering Students' Intellectual Development Using Neural Network and Expert System Technology," in *ASEE Annual Conference*, Seattle, 1998.

[11] T. M. Inc, *Boxplot Documentation,* Natick: The MathWorks Inc.