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Project-Based and Active Collaborative Learning to Teach Students About Renewable and Conventional Energy Systems

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Project Based and Active Collaborative Learning to Teach Students About Renewable and Conventional Energy Systems

Project Based Learning (PBL) and Active Collaborative Learning (ACL) techniques are used to teach students about energy conversion techniques by synthesizing both technical and social energy conversion concepts in a series of three projects. In these projects students provide solutions for providing the energy demand of a re-located island population. The PBL and ACL methods are used to provide Kern Entrepreneurial Engineering Network KEEN student outcomes such as student Curiosity, Connections, and Creating Value.

In these project scenarios, a substantial population has recently been relocated to the current island because of sea-level rise due to global warming. In addition, the population is expected to grow over the years. Using the available island natural resources, the students determine if they can meet the energy demand of a growing population for both the short-term (~5 years) and long-term (~100 years). In their analysis, the students first consider providing power through locally available natural gas and coal which has an expected finite lifetime based on the Hubbert curve for coal and natural gas extraction. The first plan then for energy is to potentially use these fossil fuel resources in conventional combustion power plants that follow thermodynamics cycles such as the Rankine, Brayton and Combined Cycles. The students are given specifications for existing power plants and are allowed to refurbish and or retrofit the components to predict energy production. Their simulation analysis is done with a series of MATLAB® codes that help automate the analysis. The students are also asked to estimate CO_2 emissions as the island population is sensitive to increasing global warming. Once the students have completed the first project, they are then asked in a second project to determine how renewable energy sources such as solar and wind energy could be used to provide the energy demand for the given population at this island location. In this scenario they are asked to calculate the solar and wind resource and apply it to specific solar panels and wind turbines while considering monthly resource variability and potential land usage. Their calculations are automated using MATLAB® codes as well. Finally, in a third project students are given up to ten emerging 21st century emerging technologies and with a Jigsaw ACL determine what technology has the potential to revolutionize energy on their island in the future.

introduction

In the 2014/2015 school year, as a newly hired professor at the University of Denver in the Mechanical and Materials Engineering Department, I was given the opportunity to create new technical electives for our undergraduate students. At the University of Denver when I arrived there were no courses in Energy Systems for our students beyond the core Thermodynamics courses, so I created a new elective known as “Mechanical Energy Systems Engineering”. A course on energy systems is important for students because it provides students with a multidisciplinary perspective, fostering critical thinking and problem-solving skills that are valuable in addressing complex real-world challenges in any engineering field. When students study the impact of different energy sources on the environment, they may conclude that sustainable alternatives such as renewable energy are more viable. Likewise, exposing students to cutting-edge technologies fosters innovation in the field, since the field of energy is constantly evolving, with new technologies emerging to improve energy efficiency, reduce emissions, and harness renewable energy sources.

Coming from an industry position, and having attended a few pedogeological workshops, I was certain that the route to engaging the students was to engage them in Project Based Learning (PBL) and Experiential Learning (EL) [1], [2]. At the same time, I also chose a textbook [3] that included addressing societal and economic impacts of using different types of energy systems along with the technical analysis. Since energy systems can be rather complex, I looked for software options for introducing the students to do a more comprehensive analysis. In this way, they could explore and synthesize the theoretical topics that were given as lectures in class. The course lectures covered conventional energy systems, nuclear energy systems, renewable energy systems, and 21st century emerging energy systems. Typical engineering students in this course are at the Junior or Senior level and have already taken Thermodynamics, Introduction to Programming, and a course in MATLAB ® [4].

The basis for the projects discussed in this paper grew from some initial first year PBL software explorations with a MATLAB® [4] for conventional and renewable energy systems. For the conventional energy systems, I provided the students with m-files (script file) for MATLAB® that could analyze thermodynamics cycles such as the Rankine and Brayton Cycle which are instrumental in analyzing conventional energy systems. The initial project used ideal gas assumptions for the Brayton Cycle and for the Rankine Cycle used the MATLAB® X Steam m-files [5] for automated water and steam table look-ups. In this project, the students were asked to analyze gas turbine and steam turbine power plants for different input conditions (pressures, temperatures, and isentropic efficiencies) and then comment on the trends for energy production and plant thermal efficiency. They used assumptions to estimate the cost and amount of fuels necessary to produce that much energy for a whole year. Likewise, the students were asked to determine if they thought the power plants would be profitable given the current price of electricity. Lastly, the students were asked to write their own code for a Combined Cycle Power Plant where the gas turbine was the topping plant, and the steam power plant was the bottoming plant being heated by gas turbine exhaust gases. By combining the Brayton and Rankine Cycle codes they could show that they were more efficient at producing energy.

For the renewable energy part of the initial projects, the students were asked to use the solar resource method/equations that were provided in the course slides as taken from various references [3], [6], [7] and provide an hourly analysis of the solar resource for a specific location for June and December and compare and contrast the two analyses. The expectation was that they would write a MATLAB® code or use Microsoft Excel®. They were then asked to determine for a given household power demand for each month, how many solar panels would need to be installed on a house and at what tilt angle.

Lastly, in a final project, the students were asked to explore emerging topics in energy conversion. In this project, each student chose their favorite emerging technology from a list of 6 to 10 emerging technologies and wrote a short summary report and presented their findings to the class. In this way, everyone could learn a little about each emerging energy topic from their classmates.

Then, in January 2018, during my teaching evolution, the University of Denver also became part of The Kern Entrepreneurial Engineering Network (KEEN). That summer I attended the KEEN Integrating Curriculum with Entrepreneurial (ICE) workshop from August 8-11, 2018. ICE workshops connect problem-based active and collaborative learning to the development of the KEEN Entrepreneurial Mindset (EM) [8]. Part of the EM skillset is to have Curiosity, Connections, and Creating Value (3 C's) [8]. As part of the ICE workshop, I proposed using my "Mechanical Energy Systems Engineering" course to develop this EM Mindset through PBL and ACL. Though my initial projects had PBL and were well-received by students, through this workshop I hoped to make my PBL more impactful and add ACL techniques.

My revamped ICE projects used story and role-playing to excite the students about determining energy conversion needs from both a societal and technical viewpoint. In addition, the three projects were woven into a single narrative that was carried through a quarter long PBL and ACL method that included scaffolding with lectures and homework. The next section describes this basic pedagogical methodology including the project specifications along with some typical results. In addition, some general comments on the course are included. These projects have been implemented in "Mechanical Energy Systems Engineering" course from Winter 2019 through Fall 2023 and the next sections describe the ICE PBL and ACL implementation.

methods

The students were introduced to the PBL theme early in the quarter during the first week. Part of the EM skillset is to have Curiosity, Connections, and Creating Value (3 C's) and the goal of these projects was to obtain both the technical and EM skillset. The following prompt is presented to the students the first week of class when introducing "Three Theme-Base Projects" along with photos representative of their fictional island (Figure 1):

> A brand-new island has been discovered/re-discovered in the Atlantic Ocean; it is believed that it may have once been the lost city of Atlantis or Themyscira Paradise Island. But currently the islands are uninhabited except for some old roads and ruins. However, it has been estimated that these islands are ideal for relocating an estimated 100,000 people that are in danger in other parts of the world of being flooded out due to rising sea levels. However, there is no infrastructure currently in place to provide power and energy to the island. It is your task to determine what are the best energy conversion techniques to provide energy to the new inhabitants in the short and long term. As the quarter progresses you will receive the specifications related to the island (topography, locations, natural resources available, etc.). Based on these specifications you and your team will decide the best short-term and long-term measures for this island and its new inhabitants.

Figure 1. Representative pictures of the potential island for population relocation.

In addition, the students are shown a video from the Washington Post You Tube Channel [9] which introduces them to the drowning Pacific Island nation of Kiribati which lies seven feet above sea level on average. Scientists say it is drowning due to sea-level rise. The Kiribati president Anote Tong in this video describes how he's planning for a future that might find his entire country submerged in the Pacific Ocean. This video is used to introduce the students to potential impacts of global warming with the reality that relocated populations needing energy infrastructure may be here sooner than we anticipated.

The hope is that that the students will develop the EM skillet through the projects in the following way:

- Curiosity: demonstrate constant curiosity about our changing world and explore contrarian views of accepted solutions. The intent is that the students will develop curiosity about different energy systems and societal impacts of using different energy systems as related to this PBL scenario. Through exploring different energy conversion methods, they are allowed to hold contrarian views about what methods will be best in the future.
- Connections: integrate information from many sources to gain insight and assess and manage risk. The intent is that the students attain the ability to gather the relevant energy conversion related information through research and analysis and will see the connections between predicted energy and societal impacts in a broader context by exploring the PBL scenario as an analogy for energy conversion in the world.
- Creating Value: identify unexpected opportunities to create extraordinary value. The intent is that the students through their analysis and research will see unexpected opportunities to improve energy systems in their PBL scenarios that may have both technical and societal impacts that will create extraordinary value.

Likewise, the students' technical skillset objectives for this course are the following:

- Identify the different types of energy conversions systems.
- Recognize the environmental issues related to energy conversion, including air pollution, the greenhouse effect, and global climate change.

- Model the performance of various energy conversion systems.
- Evaluate and compare various energy conversion systems for a new installation including cost, social acceptability, and environmental consequences.

The technical skillset maps well to the EM skillset in the PBL and ACL scenarios. The next sections describe the three project prompts for the quarter long set of projects.

Fossil Fuel Energy Island: conventional energy conversion

About three to four weeks into the quarter, the first project is introduced as “Fossil Fuel Energy Island”. In the class the students have had lectures and homework on the following three topics: “Overview of Energy Conversion Systems”, “Fossil Fuel Energy Conversion”, and “Stationary Combustion Systems”. These topics also map to similar sections in the textbook [10], [11], [12]. The additional prompts for the project are the following which enable the students to complete an energy analysis for relocating 100,000 people using conventional energy sources:

> The location of the island is approximately 30° 7'00.00 N, 42° 7'0.00" W, and it is 1500 km^2 in area (about 500 km^2 is forested). It is believed at the height of its civilization the island had 36,000 inhabitants. There is no working infrastructure currently in place to provide power and energy to the island, though it is apparent that this civilization did have some forms of energy conversion beyond wood burning in the past. Engineers have already inspected those old power plants as potential sources of immediate energy to see if they can be revived. A brief technical summary of what they found is provided below.

The project handout then describes the existing abandoned power plant specifications for both a steam power plant and gas turbine power plant. The remaining island fossil fuel resources to run these power plants are given in terms of Hubbert curve parameters as presented in [11].

The students are then asked to solve the following initial problem:

> The Energy Information Administration (EIA) estimates that a typical household locating to this island would require/desire 1000 kWh per household per month. The average household has 3.0 people. If these powerplants were made operational, would they provide enough energy for the new inhabitants in 2023? If the energy demand can be met, how many years could the status-quo energy production be performed with the island fossil fuel resources (assume any excess fossil fuels could be stored for future energy production and will not be exported). Assume that the population growth is 2% per year due to birthrate and migration to the island, and this must be accounted for in the long-term plan. How much total CO_2 will be emitted per year assuming perfect combustion of coal and methane?

Then, the students are asked to investigate alternative solutions with the given prompt:

> There is additional funding through international treaty to look at upgrades to the island infrastructure. The immediate solution is to investigate retrofits to the fossil fuel power plants which are “ancient” technology at this point. Due to the immediacy of the situation, cost is not the most important aspect of the solution, but rather efficient use of

> the remaining fossil fuel resources. The island energy solution manager would like your team to investigate the possible alternative solutions below. Your goals are to show if the methods below could possibly provide the required energy, extend the lifetime use of the fossil fuels and/or limit the amounts of CO_2 emitted. You should weigh all these design requirements in your final recommendations.

The alternative solutions they are asked to investigate include retrofitting components of each cycle to change the operating conditions. For instance, they are asked to consider superheated boilers and better isentropic efficiencies for the turbines, compressors, and pumps as well as higher temperature operating conditions. They are also asked to consider a combined cycle plant analysis. In Fall 2023, the students were also asked to consider using wood fuel pellets instead of coal as was done in converting the Drax Power Plant in England [13] to reduce CO_2 emissions.

To complete their analysis, two main MATLAB® m-file scripts are provided to the students, "Rankine_Eng.m" and "Brayton_Eng.m" which I wrote to use with MATLAB® Marina [14] or X Steam [5] m-files to provide automated fluid property look ups through scripts. The codes provided represent the ideal cycles and the students must add isentropic considerations and build the combined cycle code themselves. In addition, the students can incorporate any of the rest of the analysis into their MATLAB® codes or use output from the codes and complete the analysis in MS Excel. Once the analysis is complete, the students provide their findings in the form of a technical report and presentation which includes their recommendations for the island population's energy needs using conventional energy conversion.

Sustainable Energy Island: solar and wind renewable energy

About seven to eight weeks into the quarter, the 2nd project is introduced as "Sustainable Energy Island". In the class the students have had lectures and homework on the following additional related topics: "Solar Energy Conversion Resource", "Solar Energy Conversion Photovoltaics", "Wind Energy Conversion Resource", and "Wind Energy Conversion Design Summary". These topics also map to similar sections in the textbook [15], [16], [17]. The additional prompts for the project are the following which enable the students to complete an energy analysis for relocating 100,000 people using renewable energy sources:

> Returning to your island that you previously did fossil fuel energy analysis on, now investigate if creating electricity can be done more sustainably… Engineers have already inspected those old power plants as potential sources of immediate energy to see if they can be revived. Those engineers also know that fossil fuel resources are non-renewable and would like to also investigate solar energy (photovoltaics as a potential source) and wind power as a form of sustainable renewable energy. Ultimately, it is the desire for this island to become completely sustainable, meaning that all the electrical energy demands should be met by these two types of energy systems. Starting in 2023 with 100,000 people with 3.0 people per household, estimate the needed solar energy and wind energy assuming that initially one or the other will be installed. Since monthly energy variations may be more important for renewable sources, the monthly demand for energy in kWh is described below (it is approximately the 1000 kWh per household when averaged over the 12 months).

The project handout then describes the assumption for both solar energy and wind energy installations. The students assume that their solar installation is in an open unobstructed flat field that was previously used for agriculture and that the solar panels will be mounted in the field such that they always face south since this island is in the northern hemisphere. As a first approximation, they assume that the tilt angle is 45°, but are asked to investigate other tilt angles as well. The solar panels that will be installed are able to convert solar energy to electric energy with an efficiency of 22.8%. The students assume the solar resource method/equations that were provided in the course slides as taken from various references [6], [7], [15], [16] provide a reasonable analysis of the solar resource for this application on a monthly basis. When they evaluate a solar hour in the day the energy available is good for the entire hour. For this initial approximation, they assume that the sea-level optical depth is reasonable approximation for this island site and there are no shading or cloudy day effects. Combining the solar resource with a photovoltaic efficiency the students can estimate the number of solar panels needed to meet the energy demands.

For the solar analysis, the students are asked to provide the following:

- The length of each solar day and comments on how this may affect the amount of available energy. The lengths of the day of the shortest and longest days.
- For each month determine the total available solar energy in kWh/m^2 evaluated from sunrise to sunset in approximate hour increments for each day summed to a daily total solar energy production.
- Plots of the total available energy by day for each month in a bar graph.
- How many square meters of solar panels are needed to meet all the demand assuming each residence has a 500 kWh monthly electricity demand in the winter months (December, January and February), a 1500 kWh demand in the summer (June, July, August), and a 1000 kWh demand in Spring and Fall (March, April, May, September, October, November).
- Comments on if there is enough land on the island to accommodate this many square meters of panels.
- How many solar panels are required using a typical solar panel dimension along with a reference where they obtained their information about the typical size of a solar panel.
- Comments on how clouds at this site might affect the solar resource and how that might change the solar panel requirement.
- Comments on potential storage technologies for producing nighttime electricity if solar is the only source of electricity.

The wind resource is estimated with historical records that were found in the island archive according to the story: the previous island inhabitants recorded wind speeds with a 10 m high anemometer over the same agricultural lands to provide the yearly distribution of winds. The previous inhabitants simply enjoyed monitoring the weather and didn't realize that this information would become invaluable for wind resource estimation. The Weibull distribution parameters the students are given for the 10 m winds by month are provided below in Table 1. These actual distribution parameters were taken from a journal article [17].

Table 1: Measured wind resource in terms of Weibull parameters [17].

Weibull Distributions			
Month	**k**	**c (m/s)**	**VmW (m/s)**
January	1.64	5.64	5.04
February	1.6	6.78	6.08
March	1.82	6.73	6
April	1.41	4.83	4.39
May	1.7	5.7	5.1
June	1.95	6.35	5.66
July	2.02	7.66	6.78
August	1.87	7.37	6.55
September	1.37	4.51	4.07
October	1.57	5.48	4.87
November	1.47	4.99	4.42
December	1.45	4.88	4.41

The students are also provided with the type of wind turbines which will be installed: Vestas V82 1.65 MW turbines. The Vestas V82 is pictured in Figure 2, and performance attributes of these wind turbines are provided in Table 2 as taken from [17],

Figure 2. Typical Vestas V82 Installation [18]

Table 2. Power curve attributes of the Vestas V82-1.65 MW wind turbine [17].

Vestas V82–1.65 MW	
H (m)	78
V_I (ms^{-1})	3.5
V_R (ms^{-1})	13
V_0 (ms^{-1})	20
A(m^2)	5281
a_1	−0.00177073
a_2	0.04617394
a_3	−0.24024242
a_4	0.35436364

where H is the hub height, V_I is the cut-in velocity, V_R is the rated velocity, V_0 is the cut-out velocity, A is the swept area, a-coefficients are the fit to the power available curve given by the following expression in Equation 1:

$$P_A(V) = \begin{cases} 0, \ V < V_I \\ \left(a_1 V^3 + a_2 V^2 + a_3 V + a_4\right) P_R, \ V_I \le V < V_R \\ P_R, \ V_R \le V < V_0 \\ 0, \ V \ge V_0 \end{cases} \quad . \tag{1}$$

The students are asked to evaluate the wind energy based on a set number of hours at each wind speed based on the Weibull frequency and assume that wind speed is at that speed for the entire hour. With this given information the students are able to estimate the wind resource and the energy output of a Vestas V82 turbine by month with methods given in [19].

As part of the analysis the students are asked to include the following typical analysis:

- Plots of both the wind distribution and cumulative distribution of the wind for each month based on the Weibull parameters.
- A plot of the power curve for the Vestas V82.
- For each month the total available wind energy output for a single wind turbine (Vestas V82) in kWh.
- The number of wind turbines needed if each residence has a 500 kWh monthly electricity demand in the winter months (December, January and February), a 1500 kWh demand in the summer (June, July, August), and a 1000 kWh demand in Spring and Fall (March, April, May, September, October, November).
- The amount of land on the island needed to accommodate this many turbines assuming that the turbines need to be spaced to avoid wake effects by using a rule-of-thumb for this calculation.
- Comments on potential storage technologies for wind energy.

Lastly, the students are asked to suggest a 40-year solution to meet the energy demand that combines both solar and wind energy to meet the increasing population growth. They are asked to provide how many wind turbines and solar panels will be needed along with the estimated land usage for the next 40 years.

The last three times this project was given, I provided starter MATLAB® scripts codes that could do a full month's solar resource analysis and also a code that could take a given wind turbine along with a monthly Weibull distribution and estimate the wind energy produced for that month. So, the students were able to modify this starter code to automate a full year of analysis and put their own inputs into the models and add some post-processing. In this way, the students still needed to understand the codes, but were able to focus more on the analysis and the societal impacts. Once the analysis was complete, the students provided their findings in the form of a technical report which included their recommendations for the island population's energy needs using renewable energy conversion.

Future Energy Island: 21st century emerging energy technologies

With only two weeks left in the quarter, the final project is introduced as "Future Energy Island". This project allows the students to become their own researchers about 21st century emerging energy technologies and work in an ACL method known as a Jigsaw Activity [20]. This activity is done primarily in class and in lieu of a final exam with the students reporting out their rankings for the emerging energy technologies that are more likely to benefit their island in the future. The prompt for this activity is the following:

> Returning to your island analysis, your energy manager would like you to attempt to be a visionary in addressing your future island energy needs. Your manager believes that it is possible that the following emerging energy technologies will become available in the future for use on your island.

Usually, five emerging technologies are explored. The following are some of the emerging technologies that have been explored in the past based on a current review article available in the literature at the time [21]: Geothermal Energy Methods, Small Modular Nuclear Reactors, Small Modular Hydropower, Solar and Wind Energy in Urban Environments, Ocean Generation Mechanisms (Tidal and Ocean Currents), Concentrated Photovoltaics, Space-Based Solar, Airborne Wind Energy, Bladeless Wind Turbines, and Biomass Conversion.

Depending on the five technologies explored, additional attributes of the island are provided for the students to use in their analysis:

> In addition to the information already given to you in previous projects (fossil fuel resources, wind resource, and solar resource), it is known that the island has both substantial ocean currents and geothermal activity. The agricultural fields total 200 km^2 of high yield land for crop production, and it is expected that the population will be primarily in urban environments. There are also multiple holding ponds and small rivers and streams (these have not been completely surveyed but provide a reasonable resource for both fresh water and potential hydroelectric applications).

The students as part of this activity are introduced to why the "Jigsaw" learning technique is a great way for their team to gain subject expertise quickly in each of the above 21st century emerging energy technologies. The class is then divided into "Home Groups" and within each "Home Group" the members decide who will become an expert in each of the technologies. The team members then join other experts in an "Expert Group" and then report back to their team's "Home Group". Session 1 on Day 1 in class involves exploring the five to six technologies in their "Expert Group" and Session 2 on Day 2 involves reporting back to their "Home Group". Each group must have a minimum of five to six team members such that no technology is left undiscovered. The in-class time is about 4 hours and to keep the time efficient, I provide the students with starting references and a prompt of questions that should be explored in their expert discussions:

- What defines this energy technology--what does it do?
- What breakthroughs are needed for this technology to be viable?
- As a best guess, what is the earliest that this technology would become available for use on your island?
- How much energy production is possible from single units, multiple units, etc.?
- Based on future energy needs of the island and population growth, how much of the energy burden do you think this technology could capture? Back-of-the envelope calculation methods are reasonable way to approach this question.
- What is the approximate CO_2 contribution of this technology, considering manufacturing and production, and any other possible effects?
- Are there any other social/environmental consequences of this technology?

In their “Home Groups” they finalize their rankings of the best technologies, write a short summary report and provide a presentation of what they find on the class final exam day.

results

Fossil Fuel Energy Island: conventional energy conversion

Typical results from student projects for the “Fossil Fuel Energy Island” analysis include the initial power plant analysis and then how the retrofits increase efficiency or power output. An example plot of this type of analysis is shown in Figure 3 showing increased power output for a steam power plant and the decrease of CO_2 emissions with more efficient cycles. At the same time the students are also presenting how their resources diminish through Hubbert curves over the years in Figure 4 and with time and how the population grows while the energy demand goes up as shown in Figure 5.

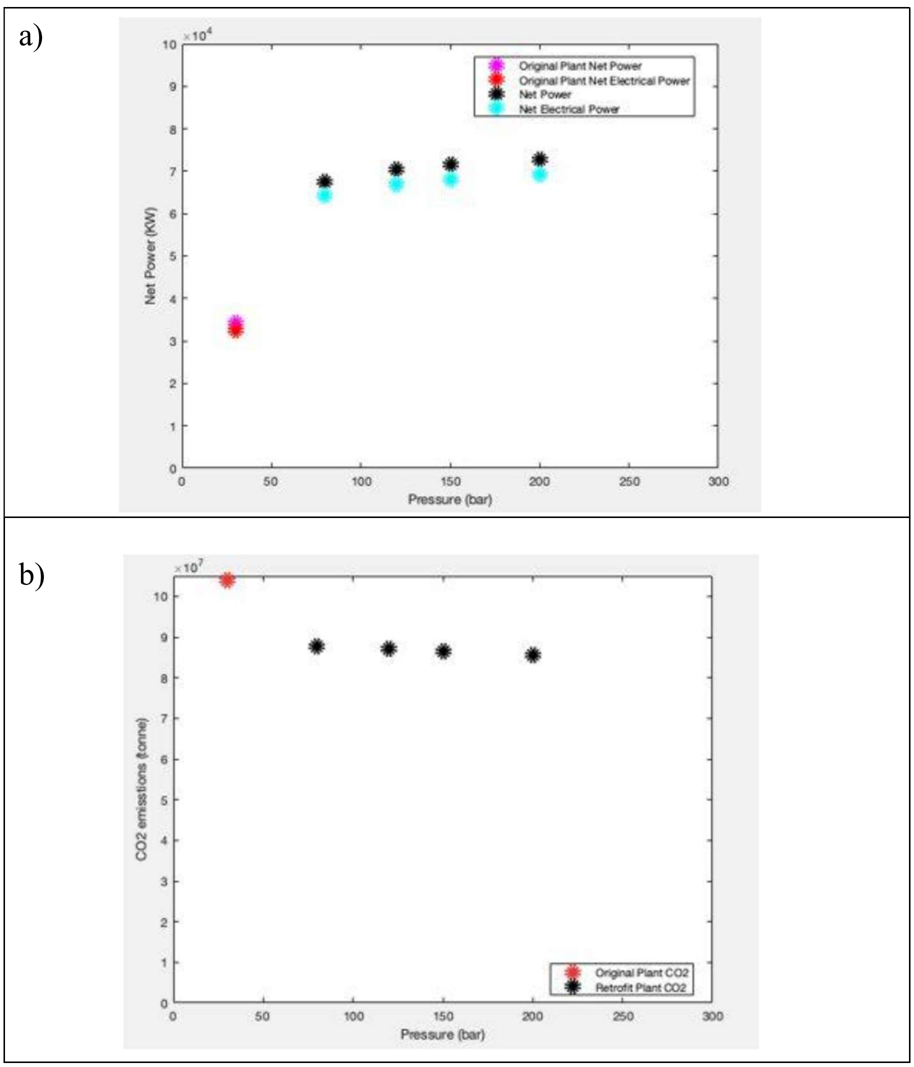

Figure 3. Example student results for the steam power plant analysis: a) net electrical output for a steam power plant with increased pressures and superheated condition and b) the estimated CO_2 emissions.

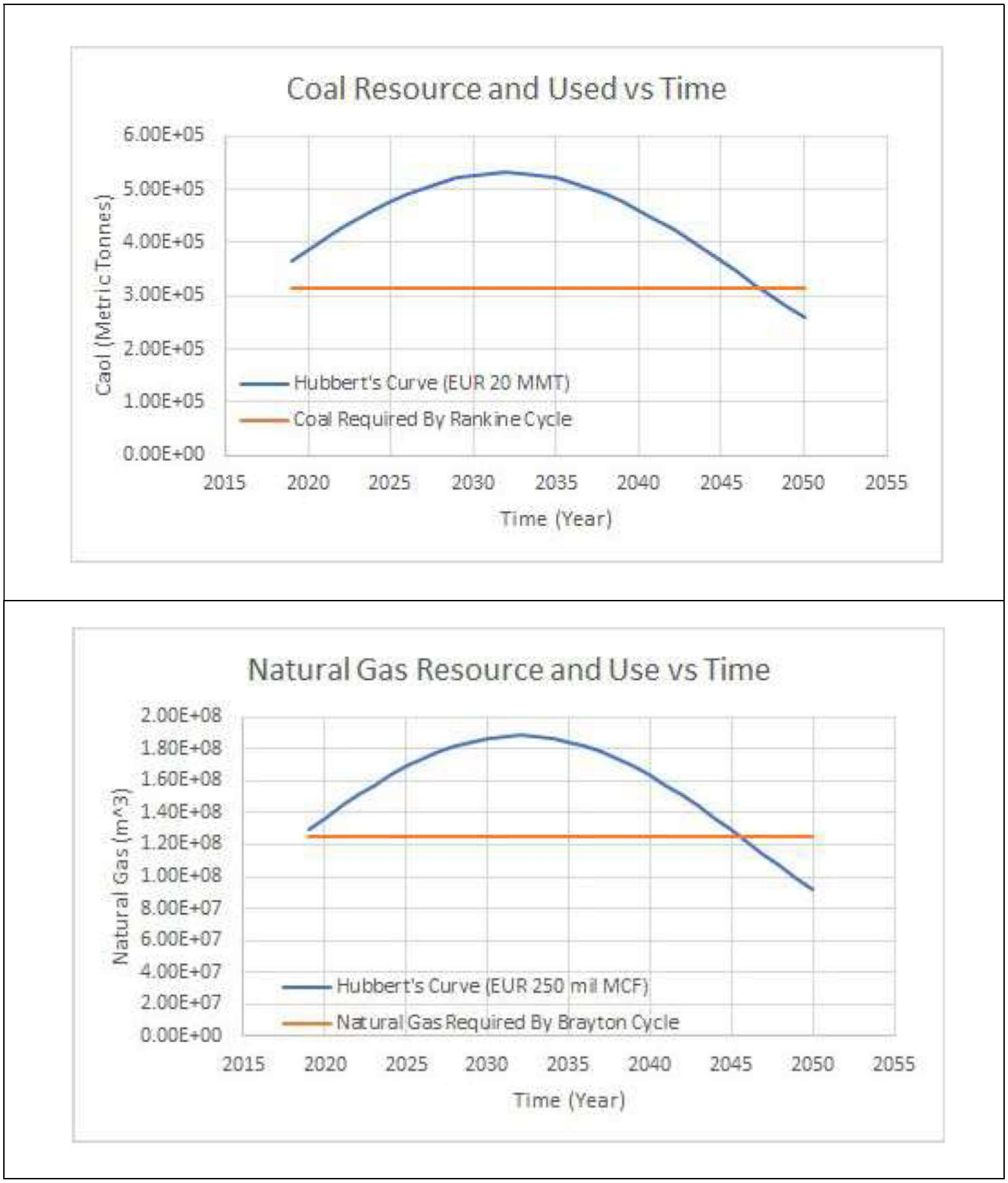

Figure 4. Example student results for Hubbert curve modeling the diminished Coal and Methane on the island plotted with the amount of fuel needed to run the power plants non-stop 365 days a year to produce the maximum energy output.

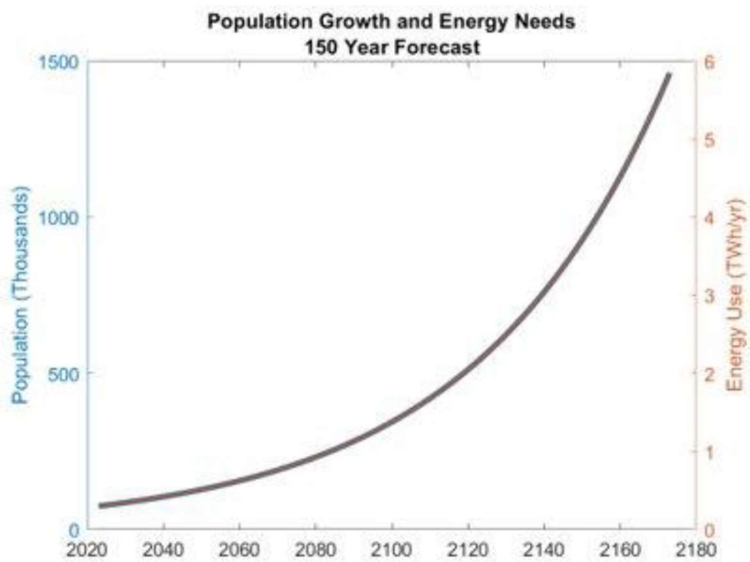

Figure 5. Example student results for population growth over the years and the expected increase in energy usage. The population growth number is on the left axis and the energy use for that population is on the right and the two scale directly.

Sustainable Energy Island: solar and wind renewable energy

Typical results from student projects for the "Sustainable Energy Island" analysis include the various plots for both the solar energy resource and wind energy resource as well as prediction for the numbers of solar panels and wind turbines that would be needed to provide the electricity demand for the island. Example plots of the student analysis for the solar analysis and wind analysis are shown in Figures 6 and 7, respectively.

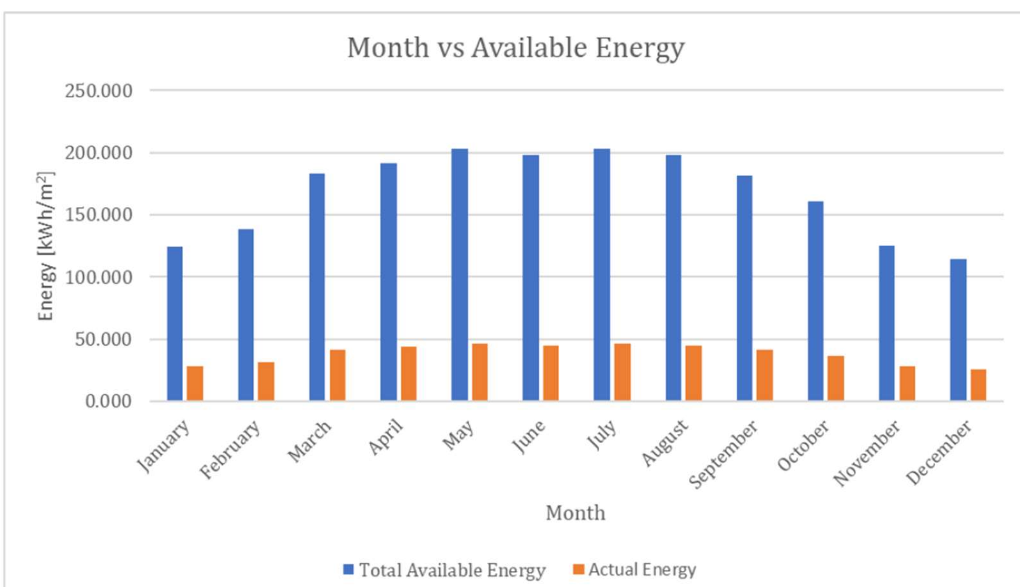

Figure 6. Example student results for the solar resource for their island location.

From their solar resource analysis, the students are able estimate the current number of solar panels needed. Typically, on the order of 400,000 solar panels are needed to ensure the demand is met every month with the given monthly residential electricity energy demand for the given year. Students also predict years into the future and find that in 150 years with population growth, they might see the electricity demand give rise to needing about 2,000,000 solar panels. For these cases they predict the amount of land needed and calculated that typically land usage might go from around 0.5 km^2 to 2.0 km^2 based on their assumptions.

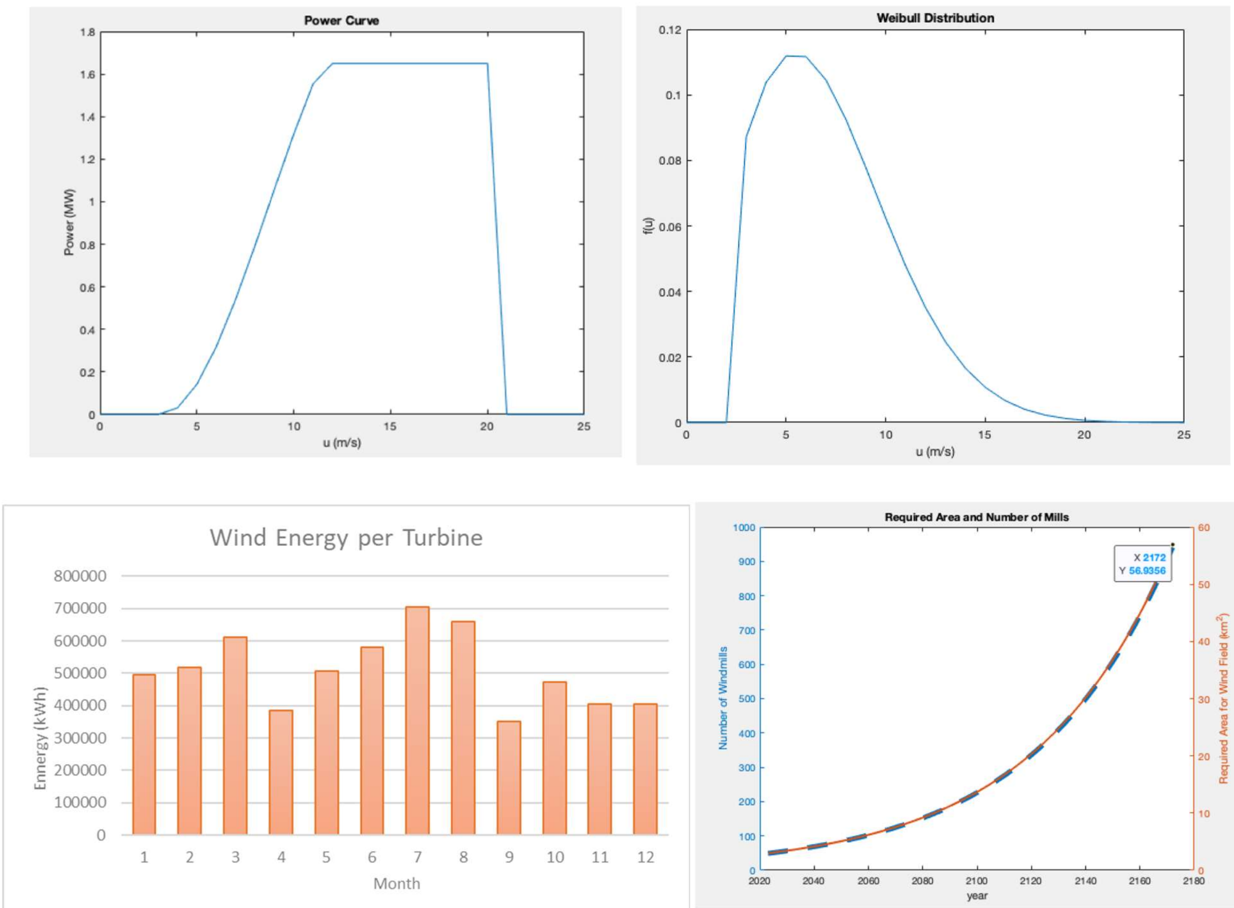

Figure 7. Example student results for the wind resource for their island location.

From their wind resource analysis, the students are able estimate the current number of Vestas V82 wind turbines needed. Typically, about 100 wind turbines are needed to ensure the demand is met every month with the given monthly residential electricity energy demand for the given year. Students also predict years into the future and find that in 150 years with population growth, they might see the electricity demand give rise to needing about 1000 wind turbines. For these cases they predict the amount of land needed from a rule-of-thumb method to reduce wake effects in the wind farm. For the first year they calculated that typically land usage might be around 5.0 km^2 but in 150 years might rise to 100.0 km^2 based on their assumptions.

Future Island: 21st century emerging energy technologies

Students primarily rank the 21st century emerging technologies (Figure 8) and provide back-of-the-envelope estimations on how this technology might work to supply all or part of the energy requirements for the island. The students at this point in the quarter have the background in both technical and societal impacts of energy conversion techniques and provide quite convincing reports and presentations. Surprising to them, each "Home Group" has ranked the technologies differently. For instance, one year every group ranked "Small Modular Nuclear Reactors" (SMRs) as the number one technology, but, in the most recent year, the students ranked this technology lower based on the fact the fissionable material would have to be imported to the island which they felt could have other societal implications. In the most recent year, the students all recognized that these SMR power plants would be efficient and scalable for future population growth, but weight other factors higher. In the case below, ocean generation won out based on presenting a more sustainable option that was also capable and required less land.

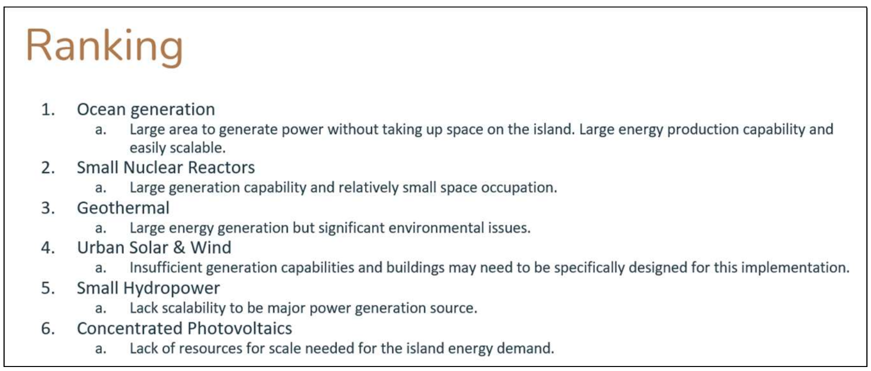

Figure 8. Ranking presented during their presentation.

discussion

The above results are simply highlights of some of the results students can obtain by learning through both the PBL and ACL part of "Mechanical Energy Systems Engineering". As shown, meaningful results for understanding both societal and technical aspects of both Renewable and Conventional Energy Systems are obtained by the students as they develop their technical skillset through PBL and ACL.

In addition, by incorporating the KEEN EM skillet through these projects the students develop Curiosity about different energy systems and societal impacts of using different energy systems as presented in their PBL and ACL scenarios. Through exploring different energy conversion methods in these three projects, the students develop curiosity about all the different ways that energy conversion can be done and what conversion methods might be done in the future.

Each project has the KEEN EM skillet of Connections by integrating information from many sources to gain insight and assess and manage risk. As can be seen in these scenarios, the students connect population growth, global warming, resource management, CO_2 emissions, and energy demand to the energy conversion technologies that they are using to provide energy to their island population.

The students exhibit the KEEN EM skillet of Creating Value. Each one of the projects give the students the opportunity to create value by going beyond the status quo and each team can provide a unique insight into what they think will work best for the island whether it is conventional energy, renewable energy, or an emerging 21st technology. Examples of this include making conventional energy systems more efficient to reduce CO_2 emissions, and providing more energy in a combined cycle that they create. In the renewable energy project, there is student realization that renewables may be ready today, and the students suggest hybrid scenarios for using both solar and wind energy. They suggest a long-term land-use plan for installing a sustainable wind and solar farm. In many instances, in contrasting with their "Fossil Fuel Energy Island", students ask, "Why are we not doing this [Renewables] for real?". Lastly in the emerging 21st century energy technology part of the project, the students rank and propose where they think future investments in energy should be done based on their research and knowledge of both technological and societal impacts.

Additional add-ons and variations to the computational experiments that continue to make this project fresh are placing the island at different latitudes and longitudes in the Atlantic Ocean, using smaller or bigger relocated populations, providing different power plant performance specifications, using different wind turbines and wind distributions, and having the students explore different 21st century emerging energy technologies.

Since developing this course with a PBL and ACL pedagogy this technical elective has become quite popular which may be indicative of students appreciating the engaging content. The initial course which was offered in Winter 2015 had 11 students and peaked at 31 students in Fall 2021. Our typical graduating classes are on the order of 30 to 40 students and only Juniors and Senior students are eligible to take the course. In a typical quarter, they have five other offerings other than this course, so around 50% or more choose to take this course before graduation. Some additional anonymous feedback from the students through student course questionnaires (faculty course evaluations) are the following:

Prompt: What were the strengths of the course?

> "Learning topic history and application is extremely helpful. Most courses focus on calculations and theory/application, but this course forces a more open mindset and pushes for a better understanding of the material" --Student, Fall 2023
>
> "The greatest strength for this course was the project based structure. It was super interesting to explore these relevant model problems and felt more like real engineering; building the critical thinking skills, reports, data simulations, etc." --Student, Fall 2023
>
> "I think the way the projects used what we learned in class directly really helped in enforcing what we learned." --Student, Fall 2023
>
> "I liked that the projects were all a continuous storyline. This made it feel more important, if not realistic." --Student, Fall 2021
>
> "LOVED this course. Professor Roney made this the best engineering course I've taken since CAD" --Student, Fall 2021

> "Projects and HWs were super helpful to understand the course properly." --Student Fall 2019

> "Very interesting material, presented in an order that kept everything interesting and new. The material seemed much more applicable to real life, and my future, than many of the other classes I have taken at University of Denver." --Student Winter 2019

The above comments focus on the PBL and EM methods and exhibit that the students are enjoying the EM skillset development as well as the technical skillset development.

conclusions

Through incorporating PBL, ACL and EM methods in three theme-based energy conversion projects, students synthesized concepts related to conventional and renewable energy conversion through using MATLAB® scripts to simulate and predict near-term and short-term energy conversion scenarios. This analysis furthered their understanding of both technical and societal impacts of energy conversion. Topics that were explored as part of these projects were Hubbert Curves for non-renewable resources, Rankine Cycle (Steam Turbine Power Plants), Brayton Cycle (Gas Turbine Power Plants), Combined Cycles and energy efficiency and CO_2 emissions related to fossil fuel burning. In addition, societal impacts of global warming in displacing populations and population growth on energy demand were addressed through these scenarios. Students were also able to synthesize methods based on renewable energy conversion with topics such as predicting solar resources, wind resources, and providing models of solar panels and wind turbines that could be used to extract this energy. Likewise, students glimpsed into the future in a third project as they quickly learned about what 21st century emerging energy technologies could change the energy landscape for their island scenario.

Lastly, the EM prompt of providing energy for a displaced population (role-playing) provided a framework for the students to first become curious about how energy is provided and how much energy might be needed. Through the prompts, students began to see the connections between energy conversion, population growth, CO_2 emissions, and resource and land management. Finally, by role playing that this analysis was for a growing population, the students saw that this work could create value by providing "better" solutions that had less CO_2 emissions or less land usage or more efficient use of the remaining resources. In this way, these PBL and ACL projects provide a means by which to produce both a technical and EM skillset. Student course questionnaires indicated that they appreciated this mode of learning. The PBL and ACL methods have been provided as Cards on the KEEN Engineering Unleashed platform [22], [23], [24].

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