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Providing Deep, Foundational Learning in an Introductory Energy Systems & Sustainability Course

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Abstract

An understanding of current energy issues is becoming increasingly important, given that energy influences many aspects of modern life. It was with this in mind that a new course entitled Energy Systems & Sustainability was developed. This work explores the impacts the course had on student understanding of energy issues. Both student work and student surveys were examined. Due to small class sizes, a more qualitative and in-depth approach was taken. From this it was found that within the area of terminology, the concepts of power and energy caused significant issues for students. Furthermore, quantifying the impacts of technology from a sustainability perspective, especially with respect to society and the environment, proved challenging. With these specific areas identified, it will be up to future work to find mechanisms to address these pitfalls in subsequent offerings of this and other related courses.

1. Introduction

Energy conversion and other resource usage are foundational topics that have far-reaching economic, societal, and environmental impacts. Furthermore, they are inextricably linked, where energy is needed to extract resources and resources are needed to convert between different forms of energy. The Center for Strategic and International Studies (CSIS) has identified "resource management" (including energy) as one of the "…most important trends shaping our world out to the year 2035" [1].

Recently universities have begun to strengthen and/or develop programs in the energy area. An example of this is the Consortium of Universities for Sustainable Power (CUSP)™, the goal of which is to "…collectively evolve and promote the curriculum develop[ment]…" in this area [2]. It was within this context that a new Sustainable Energy concentration was developed at Lake Superior State University (LSSU). This concentration is composed of courses such as power electronics, power transmission and distribution, and vehicle energy systems. In addition, a new course entitled Energy Systems & Sustainability was also developed for this concentration.

This new Energy Systems & Sustainability course is designed to provide a broad overview and allows both engineering and non-engineering students to gain exposure to these areas. There is also a separate laboratory course that is designed for the engineering students, and as such contains more technical detail. Only the lecture course is discussed in this work. The primary objectives for the course are for students to be able to:

- Objective 1: Understand and use appropriate terminology to discuss energy conversion systems and sustainability,
- Objective 2: Analyze (traditional and alternative) energy conversion systems for efficiency and power transfer, and
- Objective 3: *Measurably* evaluate the sustainability of energy conversion systems.

For the purpose of analyzing the course's impacts in a broader sense, a mixture of quantitative and qualitative methods were used to observe general trends and then examine specific areas in greater detail. The methods used included a comparison of questions from the final exam to a benchmark quiz that was taken during the first week of class, an analysis of the connections made between words/topics similar to the use of concept maps, and a tiered analysis approach to analyze subareas of sustainability as they related to describing and quantifying impacts. Lastly, a survey was distributed to the students to gather their perceptions about engineering and about other disciplines. The survey also inquired which activities (mentioned above) had the greatest impact in which of the objectives and why. Due to the small class size, these results are not repeatable. Instead, as stated, a more in-depth approach to assessment was taken.

The remainder of the paper is organized as follows: Section 2 describes the organization of the classroom. Section 3 then provides an assessment of the course outcomes. Next, Section 4 summarizes the results from the student surveys. Lastly, Section 5 summarizes this paper and concludes with the discussion of potential future work.

2. Classroom organization

As noted earlier, the objectives of the course were to help students learn and use appropriate terminology in the areas of energy and sustainability, analyze energy conversion systems numerically, and evaluate the sustainability of different energy conversion systems. These objectives were explicitly developed with Bloom's Taxonomy in mind [3], [4]. In order to promote higher levels of learning, especially for the latter two objectives, a variety of activities were developed that embodied different modes of learning. These included:

- In-class worksheets, real-world examples, and hands-on models of energy conversion systems,
- Multiple field trips to local energy conversion facilities and personal energy audits, and
- [Preferably service learning] projects completed in multi-disciplinary teams.

Each of these will be discussed further in the following subsections.

2.1. In-class and traditional class activities

The first category of class activities can be primarily classified as those that are most commonly found in a typical/traditional class setting. Most class periods consisted of a series of mini-lectures complemented by instructor examples and time for students to work on worksheets. The worksheets and examples covered both specific technical problems and more open-ended questions (especially as it related to the sustainability of different systems) and were related to current energy conversion systems whenever possible. Homework was not categorized as a separate activity because students were usually instructed to submit their worksheets as the vast majority of their homework (including completing any problems that were not finished in class). Lastly, hands-on items, such as actual photovoltaic cells and small-scale models of wind turbines, were brought in whenever possible.

2.2. Field trips and energy audits

Another method of helping students connect the theoretical concepts from class to physical systems was by enabling them to take field trips to local energy conversion facilities. The first such trip was to a site where a couple of prototype systems had been installed. One of the prototypes was an aquaculture hoop house (which provided a great analogy for how greenhouse gases work) that was used to grow both plants and fish. The energy needs of the system's fans, pumps, etc. were met by a nearby photovoltaic array. In addition to the traditional photovoltaic array, there was also a building integrated photovoltaic prototype which enabled the students to learn more first-hand about utilizing different parts of the solar spectrum for different uses (e.g. electrical energy vs. thermal energy). The second tour was of a local 30 MW hydroelectric plant. Students were able to view the several spare turbines as well as the generators and associated circuitry that was currently in use. The last trip was to a biomass conversion research system that was converting a local invasive species, reed canary grass, into biomass pellets that can be burned in a stove.

In addition to each of the tours, the students also had hands-on experience in connecting energy use to their daily lives via an energy audit. Two Kill-a-Watt® meters were made available for student use. The meters plug in to a standard 120 V_{ac} outlet. Devices then plug in, in turn, to the meter. The meter then lastly displays information about the voltage, current, power, energy, etc. - Students were to choose 10 devices from their dorm/apartment/house, take readings with the meter to estimate the power draw of each device (collecting both active-use and stand-by power readings for devices that vary), and then try to estimate their own energy use for a month based on typical amounts of time that each device is used. In the process, one student actually used his/her monthly electric bill to verify the calculations.

2.3. Project

The last significant activity of the course was a class project. For this, the students were required to work in teams of 2 – 3 members and were able to select their own topic. Projects could vary in their amount of research and design, and also could contain an optional build and test component if desired. Each team submitted a proposal of the project they wanted to pursue, after which the instructor tried to help better define the scope of each so that the project's complexity was appropriate for the allotted timeframe and background of the teams.

In this particular offering of the course, there were 6 students: two electrical engineering (EE) majors, two manufacturing engineering technology (MfgET) majors, and two biology (Bio) majors. In order to place people on teams such that their skills would complement each other, each team was assigned one EE major, one MfgET major, and one Bio major. The assignment of the teams was also based on input from all the students about which type of project they were generally interested in after some brainstorming was done as a class towards the beginning of the semester.

Teams were encouraged to pursue a project that had some service-learning component where the results would be useful to the campus and/or local community. As a result of some recent automobile-pedestrian accidents on campus, the first of the two teams selected to pursue the design and construction of solar-powered lighting for pedestrian crosswalks. The team had to take into account the amount of solar energy available at different potential locations and then determine an appropriate size of the solar panel and amount of (battery) energy storage needed given the LED loads and the local weather patterns during the months of peak cloud cover. The second team, meanwhile, examined the feasibility of purchasing and installing a bike generator in one of the campus workout areas that would be able to charge portable devices (tablets, smartphones, laptops, etc.). The team had to similarly ensure that the generator would produce enough energy to charge the devices and that a battery attached to the system had sufficient storage. The purpose of this battery was to enable device charging even when the bike was not in use.

At the end of the semester, each of the groups presented their results in a forum that was open to the entire campus community. Each of these presentations included a live demonstration of a prototype system based on their work to-date. They also documented their work in a formal report and provided items such as formal design files and user's manuals where appropriate.

3. Assessment of outcomes

Each of the classroom activities described in Section 2 had different grading mechanisms which had a combination of participation, presentation/communication, and technical points associated with them. For this paper, a different set of evaluation mechanisms were utilized that focused strictly on the student's understanding based on what they communicated in writing. Given the small number of students in the class (6 total as previously mentioned), a more comprehensive approach to assessment was chosen. The approach was comprised of pre-/post- test scores, analysis of understanding in a concept-map like approach, and a tiered approach to look at different levels of understanding. The goal of all these evaluations was to look at student comprehension from multiple angles and to also gain greater detailed information about specific areas of weakness. When reviewing the results, it is important to note that one of the Biology students did not complete the benchmark activity nor the feedback survey, so for Section 3.1 and Section 4, there are only 5 samples instead of 6.

3.1. Comparison of benchmark quiz and final exam

The first analysis completed was the comparison of pre- and post- class evaluations. During the first week of school students were given a benchmark quiz that served as the former tool, while the final exam for the course served as the tool for the latter. Within these two evaluations, topics from each of the three course objectives were repeated on both so that a direct comparison of the comprehension gained from the course could be determined. While similar in content, the wording of each benchmark quiz and analogous final exam question was changed in each case to avoid misleading results, where students would be scoring better but only due to memorization.

The benchmark quiz questions were graded on a 0 to 1 scale in increments of 0.25. A grade of 0.75 was used as a threshold for an acceptable understanding while a 1 indicated that there were no errors at all in the answer. A 0 indicated no answer or no relation of the answer to the question. Lastly, 0.25 and 0.5 indicated that there was some level of understanding by the student, but that it was not up to an acceptable level. The final exam was graded with similar reasoning and the same scale for the purpose of this paper. The results of the question comparisons can be seen in Figure 1. Further detail as well as the types of questions from which the data was taken can be viewed in Table 1. It is important to note that some of the questions used true/false or multiple choice answers. Such questions resulted in binary grading (0 or 1) if no work was shown.

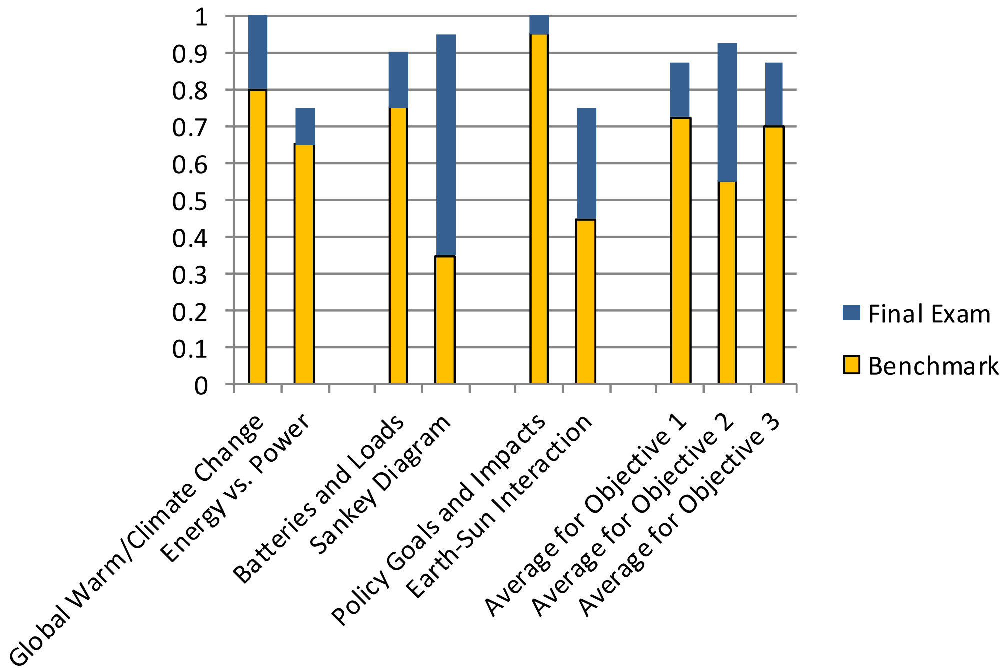

Figure 1: Benchmark ("Pre-") and Final Exam ("Post-") Results

Figure 1 shows the results broken down by course objective. The first two left-most bars depict the questions that pertained to Objective 1, the next two bars align with Objective 2, and the third set of two bars relate to Objective 3. The average of the sets of bars is then summarized at the far right.

From this figure, a number of observations can be made. First, within the terminology category (objective 1) students struggled with the use of the terms "energy" and "power." This particular question had the lowest final exam score and the second lowest gain (where policy had the lowest, but that was, in part, due to the fact that it started out so high on the benchmark quiz). This confusion of terms was also noted during the final presentations from the projects. While this may arise from society's often misuse of the terms, the specific cause and some potential solutions to the issue for subsequent course offerings remain open questions.

Another observation is that the second objective, which dealt with the technical analysis of energy conversion systems, had significantly higher gains (it started out the lowest value and end with the highest, too). This low starting value is not entirely surprising because most students would not come in with the specific technical knowledge. Whereas students might, however, have some knowledge about the terminology (Objective 1) in the fields of energy and sustainability, and/or have studied some aspects about sustainability (Objective 3), and/or be able to critically analyze what some of the impacts of different systems are even if they have not formally learned them previously. The fact that this objective had the largest gain is also not entirely surprising. The majority of the students in this course were engineering majors and most engineering majors are good at technical analysis.

Table 1: Benchmark Quiz and Final Exam Question Topics, Types, and Mapping to Objectives

Topic	Type of Questions	Objective
Global Warm/Climate Change	True/False	1 (Terminology)
Energy vs. Power	Multiple Answer	1
Batteries and Loads	Short Numerical Answer	2 (Technical Analysis)
Sankey Diagram	Benchmark: Sentence(s) Answer Final Exam: Multiple Choice & Sentences Answer	2
Policy Goals and Impacts	Sentence(s) Answer	3 (Sustainability Analysis)
Earth-Sun Interaction	Sentence(s) Answer	3

3.2. Final exams: energy-sun interaction

Another method used to assess the learning outcomes of the Energy Systems & Sustainability course and to help determine student understanding involved the creation of concept maps (cmaps). A concept map is a technique of graphically organizing information to show how various items are related to each other. There has been significant research into the creation of concept maps as well as their use in assessing student learning [5], [6], [7]. Concept maps have also been used to assess student learning in the specific area of sustainability [8], [9], [10].

For one of the sustainability problems on the final exam, the students were asked to describe the interaction between the earth and the sun. Specifically, they were instructed to use only four to five sentences and to include the following terms: {reflect, absorb, atmosphere, surface, greenhouse gas, radiation, ultraviolet (UV) light, visible light, and infrared (IR) light}. To assess student learning for this problem, a cmap technique was utilized where the students' answers were analyzed based on the connections that were made between the terms. An example of one connection (which the students did quite well on) was that the albedo was a measure of the reflectivity of an object. When an appropriate connection was made in the description, a value of 1 was entered; if no connection was made, the value remained 0; if an error was made in describing the connection then a value of -1 was entered.

Table 2 shows the compiled results (from all students) of this connection analysis while Table 3 holds a similar analysis for the instructor's solution. In addition to the aforementioned albedo-reflect[ion] connection, students also made a lot of appropriate connections between the different wavelength of light categories. Areas where students made more erroneous connections and/or failed to make connections were how radiation was absorbed, the specific relationship of albedo with different objects, and the interaction of different substances with ultraviolet light.

Table 2: Summation of *Student* Connections between Topics

	Albedo	Reflect	Absorb	Atmosphere	Surface	Greenhouse Gas	Radiation	UV Light	Visible Light
Reflect	6								
Absorb	0	2							
Atmosphere	0	3	0						
Surface	0	3	3	2					
Greenhouse Gas	0	0	0	0	0				
Radiation	0	2	2	3	1	2			
Ultraviolet Light	0	0	0	0	-1	0	2		
Visible Light	0	2	1	0	0	0	2	4	
Infrared Light	0	0	0	0	1	1	3	4	4

Table 3: Instructor Connection between Topics

	Albedo	Reflect	Absorb	Atmosphere	Surface	Greenhouse Gas	Radiation	UV Light	Visible Light
Reflect	1								
Absorb	0	0							
Atmosphere	0	1	1						
Surface	0	0	1	0					
Greenhouse Gas	0	0	1	0	0				
Radiation	0	1	0	0	1	1			
Ultraviolet Light	0	0	1	0	0	0	1		
Visible Light	0	0	0	0	0	0	1	1	
Infrared Light	0	0	1	0	0	1	1	1	1

In order to ensure that such an analysis was calibrated to the original scoring of the exams, Table 4 was constructed based on the total number of connections for each of the samples of work.

Allowing for two connections per sentence with one error would give (5*2 – (1- (-1))) = 8. This aligns with the average of 8.67 in Table 4 which, in turn, correlates to the average score on that exam problem (75%) residing near the average passing grade (73 - 76% C grade as defined in the course syllabus).

Table 4: Connections from Concept Map-Like Analysis

	Number of Connections
Sample1	10
Sample2	7
Sample3	5
Sample4	11
Sample5	9
Sample6	10
Average	8.67
Realistic Maximum	15 – 20

In theory, students could make a connection between all combinations of words which would be $\frac{n(n+1)}{2}$ connections. Given the nine words that they were to use, this would result in a maximum of 45 connections. The stipulation of only using four or five sentences, however, limits the number of connections that would be written down. Based on the instructor's own connection total of 17, a realistic maximum is estimated to be in the range of 15 – 20 connections.

3.3. Final exams: sustainability analysis

The last area explored in-depth is the students' ability to analyze various technologies in terms of the three broad areas of sustainability: the environment, society, and economy. In order to assess this work, a tiered approach was used that further examined the students' ability to analyze each of the three areas *measurably*. This approach is shown visually in Figure 2.

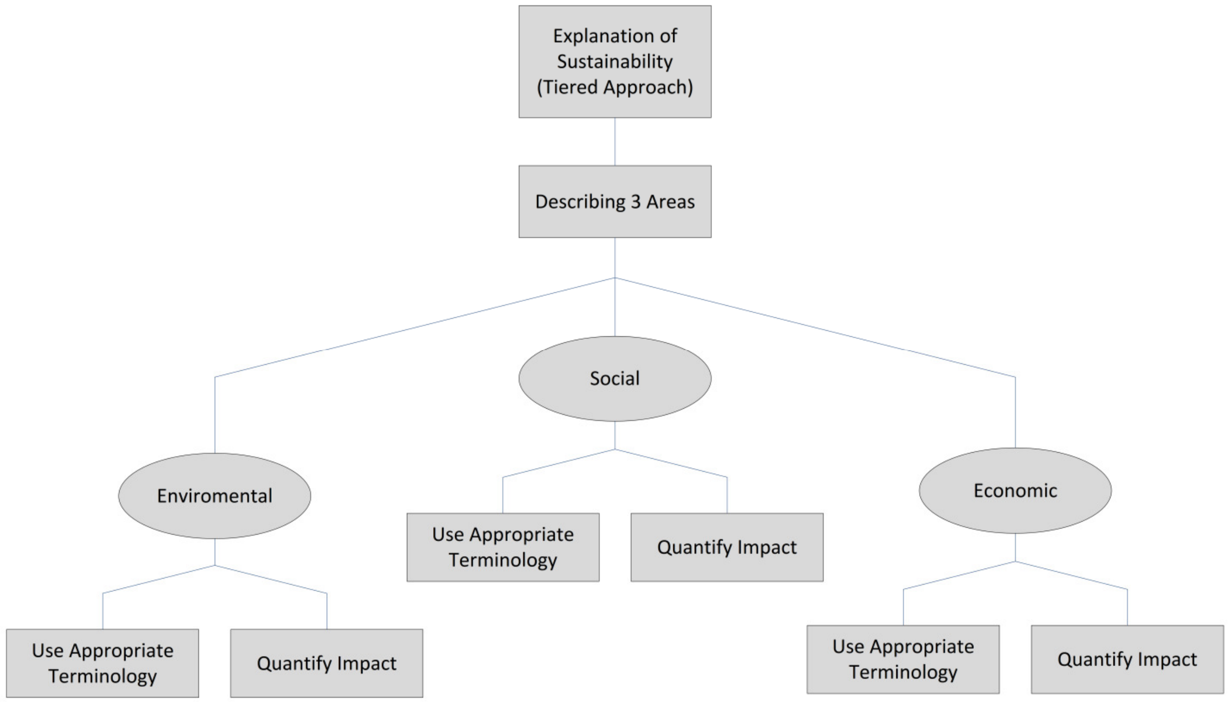

Figure 2: Tiered Approach to Determining Weaknesses of Sustainability Analysis

For the exam, students were given a scenario of a wind farm installation and asked to analyze both the potential positive and negative impacts in each of the three areas of sustainability. Furthermore, they were requested to comment on how they would measure this impact and include the units of the measurements. Based on this tiered approach from Figure 2, the student work was rated in each of the subcategories on a scale of 0 (no connection, no appropriate quantification, etc.) to 1 (complete and direction connection, etc.). The results of this analysis to-date are shown in Table 5. As can be seen, the terminology was the relative strong point in the students' analysis whereas the use of appropriate units in measurements was by far the lowest. If the positive and negative analyses are averaged, as seen in the right-most column, the economic analysis has the highest value (~0.77), followed by the environmental analysis (~0.72) and then the societal analysis (~0.69). This is an interesting result given that the two non-engineering students in the class were from biology. Even though they presumably had more background in the area of the environment (and it came up a lot in class conversations), quantifying impacts (especially the positive ones) in that area was still an issue for the class.

Table 5: Details of Student Sustainability Analysis

	Examples' Connection to Area	Measurement Appropriate to Area	Terminology Appropriate to Area	Units Appropriate to Measurement	Average
Environment(+)	0.63	0.79	0.75	0.17	**0.58**
Environment(-)	0.88	0.92	1.00	0.63	**0.85**
Economy(+)	0.79	0.83	0.88	0.67	**0.79**
Economy(-)	0.67	0.83	0.88	0.63	**0.75**
Society(+)	0.58	0.58	0.75	0.42	**0.58**
Society(-)	1.00	0.71	0.88	0.63	**0.80**
Average	0.76	0.78	0.85	0.52	0.73

4. Survey of student opinions

The final assessment method used in this work involves examining the results of a student survey. The survey consisted of a total of 21 questions. The first few questions (1-7) asked students to rate how much the course influenced their opinions on various energy and sustainability issues. These questions were the same as those presented in [11]. The next question (8) was a short answer and asked the students to comment on the course, after which a logistical question (9) was included to make sure they understood the upcoming change in ranking format. The next set of questions (10-19) asked students to rate how helpful different course activities were towards the learning outcomes. The final questions (20-21) were short answer where students explained why the course activities were helpful or not helpful towards their learning.

4.1. Impacts on student perceptions, skills, and understanding

The first set of questions on the student survey had the student's rate the effect this course had on their understanding of different issues. Specifically, the survey asked:

Because of this class, I...

1. I am more likely to [continue to] pursue an engineering degree.
2. I have more respect for the work that engineers do.
3. I have more respect for the work that non-engineers do.
4. I feel more confident in my ability to solve problems through research, reasoning, and math.
5. I have more of an understanding of the global nature of *engineering* issues.
6. I have more of an understanding of the global nature of *sustainability* issues.
7. I have more of an understanding of the global nature of *energy* issues.

Students rated each question on a scale between 0-4.

- 0 = Do Not Agree At All
- 1 = Agree to a Very Small Extent
- 2 = Agree to a Moderate Extent
- 3 = Agree to a Large Extent
- 4 = Agree to an Extremely Large Extent

A summary of the results can be seen in Table 6 where the values in each row are generally colored from lowest (red) to highest (green). It is difficult to draw any specific conclusions from this data due to the small sample size. However, students agreed with question 7 (understanding of the global nature of energy issues) the most, and it also had the least variation. Interestingly question 3 (respect for the work that non-engineers do) was rated highly by the engineer students and quite low by the non-engineering student. Obviously with only a single data point, that result is not meaningful but it is something to look into in future work. On the other hand students rated question 4 (confident in my ability to solve problems through research, reasoning, and math) the lowest, even though one of the students had mentioned in the open-ended questions that the course "…provided systematic approaches and critical thinking techniques to solve problems." This is another item that should be examined in future work.

Table 6: Student survey results for questions 1-7

	Question	1	2	3	4	5	6	7		
	Major	Pursue Eng Degree	Respect for Eng	Respect for Non-Eng	Solve Problems	Global Eng Issues	Global Sustain. Issues	Global Energy Issues		Average
Sample 1	Non	2	3	1	2	2	2	3		2.14
Sample 2	Eng	4	4	4	3	4	4	4		3.86
Sample 3	EngT	3	3	4	3	4	3	4		3.43
Sample 4	Eng	4	4	4	3	3	4	4		3.71
Sample 5	EngT	3	3	3	3	3	4	4		3.29
										Overall Average
Average		3.2	3.4	3.2	2.8	3.2	3.4	3.8		3.29
STD Dev		0.84	0.55	1.30	0.45	0.84	0.89	0.45		
Median		3	3	4	3	3	4	4		
FT Mean		3.33	3.33	3.67	3	3.33	3.67	4		
Hi		2	3	3	0	2	3	5		
Lo		2	2	2	4	2	1	0		
Difference		0	1	1	-4	0	2	5		

4.2. Helpfulness of different course activities

The next set of questions on the student survey had the student's rate the effect different course activates had on the learning outcomes of the course. Specifically, the survey asked:

The primary course objectives were for students to be able to:

- Understand and use appropriate terminology to discuss energy conversion systems and sustainability,
- Analyze (traditional and alternative) energy conversion systems for efficiency and power transfer, and
- Measurably evaluate the sustainability of energy conversion systems.

Rate how helpful the following activities were in terms of the above course objectives:

10. Performing energy audits via the Kill-a-Watt® device
11. Visiting local hydro, photovoltaic, and biomass energy conversion facilities
12. Having in-class, hands-on items such as photovoltaic cells and wind turbine models
13. Completing worksheets/homework that cover generic technical problems
14. Completing worksheets/homework that cover real-world technical problems
15. Completing worksheets/homework that cover more open-ended questions (for example, the sustainability analysis of different energy conversion systems)
16. Completing a [preferably service learning] project
17. Working in multi-disciplinary teams
18. Completing and obtaining feedback from quizzes and exams during the semester

Students rated each question on a scale between 0-4.

- 0 = Not Helpful at All
- 1 = Minimally Helpful
- 2 = Moderately Helpful
- 3 = Very Helpful
- 4 = Extremely Helpful

A summary of the results can be seen in Table 7. From this data it can be seen that question 14 (real-world technical problems) was rated as being the most helpful towards the course outcomes. However, both questions 13 & 15 (generic technical problems & open-ended questions) were also rated highly. These results were reinforced in the comments made in questions 20 & 21 and are not unexpected as engineering students are generally interested in working examples and solving problems. Question 18 (quizzes and exams) had the lowest average rating but had the second largest standard deviation. This is possibly due to students' general aversion to quizzes and exams and/or a lack of understanding of how feedback from formative assessment can enhance learning. Somewhat interestingly each student gave the same rating (3) for question 11 (tours of energy conversion facilities).

Table 7: Student survey results for questions 10-19.

	Question	10	11	12	13	14	15	16	17	18	19	
	Major	Energy Audit	Tours	Hands-on Items	Generic Technical Problems	Real-World Technical Problems	Open-Ended Questions	Project	Multi-Disc Team	Quizzes and Exams	PLQs	Average
Sample 1	Non	2	3	2	2	3	3	3	3	2	2	2.5
Sample 2	Eng	3	3	4	4	4	4	3	3	4	4	3.6
Sample 3	EngT	3	3	3	3	3	3	0	1	2	1	2.2
Sample 4	Eng	4	3	2	4	4	4	3	3	0	3	3
Sample 5	EngT	3	3	3	4	4	3	4	3	3	2	3.2
												Overall Average
Average		3	3	2.8	3.4	3.6	3.4	2.6	2.6	2.2	2.4	2.9
STD Dev		0.71	0	0.84	0.89	0.55	0.55	1.52	0.89	1.48	1.14	
Median		3	3	3	4	4	3	3	3	2	2	
FT Mean		3	3	2.67	3.67	3.67	3.33	3	3	2.33	2.33	
Hi		2	2	2	4	5	4	2	1	1	1	
Lo		2	1	1	1	0	0	2	1	2	2	
Difference		0	1	1	3	5	4	0	0	-1	-1	

5. Conclusions and future research

In summary, this paper examined student learning in a new Energy Systems & Sustainability course. There were several weak areas identified by the overall analysis and more detailed subsequent analysis of the students' understanding of various topics. One major issue that needs to be addressed in future offerings is to help students better form a concept of the difference between power and energy. It was also noted that students tend to think about technologies as either "good" (e.g. renewable energy) or "bad" (e.g. fossil fuels) by default without any quantifiable analysis as to why. As a result, discussing how to measure such impacts, especially as they relate to the areas of society and the environment, earlier in the course will be critical.

Based on the lessons learned from the course and subsequent analysis, several avenues for future research have been identified. The first idea is to integrate some simulation tools for the engineering students who have that background to help enhance understanding and potentially increase student interest (this will likely be done more in the lab portion given the additional engineering prerequisites that it has).The second idea is to have students explicitly draw concept maps at the beginning and end of the course for the sake of (1) students becoming more aware of the usefulness of such tools and (2) having a more direct measurement of the connections that students are able to make (as opposed to the current *implied* approach). Furthermore, it would be very useful to solicit the help of one or more experts to have them construct a concept map. This information could then be compared and aggregated with the instructor's concept map to provide a more robust standard for comparison against the student concept map connections. Another area of future research is a more detailed analysis for one or more technical problems. A concept map that is based on the steps to solve a problem, such as those utilized by Hill & Plantenberg [12] could then be used. Lastly, while it was useful to analyze sustainability in the context of the three areas of the environment, society, and the economy, the analysis could be expanded to include other categories such as the 10 denoted in Segalas [13].

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