Building Core Energy Literacy Skills for Students Using WeBWork Problem Sets

Taco Niet
Sustainable Energy Engineering,
Simon Fraser University

Trevor Barnes
Sustainable Energy Engineering,
Simon Fraser University

Abstract

Energy literacy is a person's ability to critically analyze and understand the energy system to make informed decisions. Utilizing this skill in academia and industry is becoming increasingly important to develop effective climate change solutions. Our study investigates if the addition of online energy literacy problem sets in a first-year engineering course curriculum increases the students understanding of the topic. We find no statistically significant evidence that our intervention improved or reduced the student's understanding. However, due to our small sample size this is not a surprising result. More notably, our study employs numerous course design methodologies to improve student engagement in learning energy literacy concepts. We also highlight the serious lack of energy literacy focused education research currently available.

Introduction

Developing solutions to combat climate change is an exceedingly difficult problem that requires innovation from all members of society. Energy researchers and industry professionals need a fundamental knowledge on how to analyze and evaluate the energy system if they are to contribute effectively to these solutions. University level science, technology, engineering, and math programs (STEM) may enforce energy concepts in varying degrees, but little research exists on what concepts students retain and understand that directly relate to energy literacy.

Defining energy literacy can be difficult given the broad scope of topics that energy encompasses. In our study, we follow the United States Office of Energy Efficiency and Renewable Energy's key points to measure if a person is energy-literate [1]. Included in these points are if a person "can trace energy flows and think in terms of energy systems", if a person "knows how much energy they use, for what purpose, and where the energy comes from", if a person "can assess the credibility of information about energy", and if the person can "make informed decisions based on an understanding of impacts and consequences”. Developing these energy literacy skills early in a student’s STEM education will enable them to relate their work and studies to key technical issues surrounding the energy system.

Our study measures how the intervention of adding online energy literacy-focused questions to a first-year engineering course affects the student’s energy literacy knowledgebase. Regardless of the results, this study contributes to the limited literature on energy literacy education through making all content openly available. This provides a starting point for other researchers to conduct their own energy literacy education studies. Moreover, we discuss and implement a variety of teaching techniques to improve student engagement and knowledge retention. These methods are subject independent and can help guide course development in both STEM and non-STEM fields.

Literature Review

Energy literacy covers a wide range of topics that can be applied at varying scales; therefore, students are expected to have misconceptions about the topic [2]. Researching, implementing, and documenting instructional methods to help correct these misconceptions is imperative in higher education [3], [4]. Numerous techniques have been cited to improve student engagement in learning a topic, which in turn can lead to increased knowledge retention. The literature reviewed in this section discusses a variety of these techniques, including gamification mechanics, increased peer collaboration, and improving the relevance of course material. Furthermore, literature on concept inventories is reviewed, as they are a common method to measure the student's understanding of a course. Specific emphasis is placed on energy literacy and STEM-focused studies in this review.

Gamification

Gamification techniques in STEM education research are well cited as a method to improve student engagement [5]–[8]. Goehle [6] explored how video game mechanics, such as leveling and achievements, can improve undergraduate student engagement with online math homework sets. He incorporates leveling, the concept of “gaining experience points by performing some task”, to a class through providing extra credit points based on the number of online problems completed. Moreover, achievements are introduced which represent goals to earn extra experience points. Goehle’s students actively engaged and enjoyed the gamification mechanics introduced; however, he cautions that his study does not provide sufficient evidence to correlate the gamification mechanics with increased performance or retention of knowledge.

The distinction between student engagement and student performance in gamification studies is a conclusion supported by other authors. Both Coleman [7] and Carey and Stefaniak [8] studied how to improve the engagement of undergraduate students through the use of digital badges. Coleman's study highlights that a badging system must closely relate to the students' own interests and goals if they are to remain effective. Additionally, Carey and Stefaniak conducted interviews to understand "what factors contribute to increased motivation for badge earners" and "what design considerations need to be made when developing badge systems". The authors conclude that badging and reward systems need to be carefully configured to achieve student acceptance, however, the knowledge retention effects of such systems in STEM disciplines still deserve more research.

Introducing a customized energy literacy-focused gamification mechanism and badging system is outside of the scope of this study. The cited literature suggests that significant thought and deliberation must take place to build a quality badging system, yet the timeframe of this study does not allow for this. Therefore, implementing our online energy literacy questions in a system that supports gamification mechanics is more important then implementing the actual system. Gamification mechanics can then be introduced through future work opportunities, as discussed in the conclusions, to further improve student engagement with learning energy literacy.

Student Collaboration

Peer collaboration in higher education is a necessity with widely mentioned learning benefits [9]–[13]. However, with the increased prevalence of online communication platforms, collaboration is being used as a method to exchange answers without exchanging ideas on how to solve problems. Brimble [14] conducted a literature review to understand why students cheat and suggests mitigation techniques. In particular, he highlights that if assignments are generic with easy-to-get answers, this may invite cheating as students will "see little educational value in completing the task". Therefore, it is imperative that thought be placed on how we implement student collaboration mechanisms.

Our study encourages collaboration without cheating through the use of random variables and unlimited attempts at solving problems. The randomized variable values in problem statements encourage students to discuss their processes rather than final answers, since the answers are only useful to that student. Therefore, each student will need to complete the process for him or herself to receive full marks. Furthermore, allowing unlimited attempts on the questions will encourage students to discuss and try different techniques to solve problems without worrying about mark deductions. This not only helps open discussions and brainstorming, but allows students to self-evaluate their own understanding of the topic [15], [16]. These peer collaboration techniques are expected to increase engagement and reinforce topics introduced in lecture, and are enhanced by providing students time within the lecture/tutorial for discussion of the online questions.

Topic Relevance

Energy literacy by definition involves having a practical understanding of the energy system. Skills such as knowing how much energy you consume and tracing the flow of energy are requirements to be considered energy literate [1]. Structuring course material to focus on these practical applications is a key component of our study, as increasing the relevance of course material has been shown to improve skill development, student satisfaction, and student engagement [13], [17]–[19].

Energy systems are large and complex; therefore, it can be easy for students to feel overwhelmed if material is not appropriately presented. Thibaut et al. [19] conducted a study on STEM student motivation and notes the importance of linking problems to “current-events or contemporary issues”. Designing energy literacy problems that relate to the personal experiences of students, or that are derived from real-world issues, can help in learning the complexities of the energy system. Moreover, as discussed previously, if students can personally connect with questions they will be less likely to cheat. Building problem sets that directly relate to a student’s energy needs, or that resemble a real-world energy problem, will encourage students to work through the difficulties of understanding the energy system as they can personally connect with the issues.

Concept Inventories

Measuring how instructional content effects a student's knowledgebase is essential to guide the development of a curriculum. Concept inventories are tests that are “designed to efficiently evaluate students’ conceptual understanding of a particular area of learning” [20]. Administrating a concept inventory at the beginning and end of a course (or topic area) can gauge the effectiveness of curriculum and instructional material by comparing results [21]. Moreover, concept inventories can be used to understand how different teaching methods affect a student’s conceptual understanding of a topic, as well as understanding what misconceptions about a topic have not been addressed [22].

STEM fields in particular benefit from the use of concept inventories [20], [23]–[26]. Typical end-of-chapter problems in early undergraduate STEM textbooks involve process-based steps that require the use of models and algorithms introduced in the preceding chapter. Students can often complete these problems following similar textbook examples without gaining a deep understanding of what they are doing. Concept inventories differ as they aim to test the students conceptual understand the concept instead of a student's ability to apply an algorithm. It is imperative in STEM education to correct fundamental concept misconceptions in early-year undergraduate classes, as senior level classes will heavily rely on these concepts.

Energy literacy spans numerous STEM disciplines; however, there is no dedicated concept inventory on the topic. This may be due to the open definition of energy literacy, or because there are currently few dedicated classes for teaching energy literacy. For existing concept inventories to remain valid, they must be used in full with original question wording and order [22]. Therefore, piecemealing an energy literacy concept inventory together from different STEM concept inventories may result in missing topics or inconsistent question phrasing. Dedicated research must occur to develop an energy literacy concept inventory that can correctly identify subject misconceptions.

Designing and validating a concept inventory is a challenging and extensive process. Concept inventories are usually multiple-choice tests, where each question tests a single topic only. The incorrect answers are worded “based on research into the way students think” and help categorize misconceptions about the topic [22]. As described in detail by McGinness et al. [20], a published high-quality concept inventory must incorporate multiple iterations of feedback from national and international experts, as well as feedback from sample student groups. Furthermore, the validity of a published concept inventory should be further supported by a system that shows how the test aligns with the required learning goals [21].

Administering a concept inventory to evaluate if our online assignment sets correct misconceptions about energy literacy is useful to improve result robustness. However, given the significant time and effort requirement needed to develop a valid energy literacy concept inventory, it does not fit within the scope of this project. As will be discussed in the conclusions, developing an energy literacy concept inventory for first-year STEM education represents a major milestone in filling this research literature gap.

Methods

Our study measures improvements in energy literacy skills made by first-year students in the Simon Fraser University (SFU) Sustainable Energy Engineering Program (SEE) given updated instructional material. We implement a treatment of adding online energy literacy problem sets to reinforce the concepts discussed in lecture. To measure the effects of treatment, we compare the marks of an energy chain assignment administered in a reference year with those of the treatment year to determine any statistical improvements. Each part of this process is discussed below.

Online Problem Sets

The open-source online homework platform WeBWork [27] is used to curate and host the problem sets used in this study. WeBWork allows instructors to browse their open problem library (OPL) [28] of more than 20,000 STEM-focused problems to create custom assignments. In addition, instructors and researchers can develop their own problems and submit them to the OPL for hosting and sharing. WeBWork also supports numerous topics discussed in the literature review, such as gamification and badging mechanics, random variable value functionality, and problem modification. This allows us to modify existing problems and relate them directly to SFU students, such as calculating the electricity generation for a power plant geographically close to them.

Browsing the OPL highlighted similar findings to the concept inventory search; there is little to no dedicated energy literacy-focused instructional material. For example, questions exist that relate to energy balance and electrical power, however, they are approached from a thermodynamic and electrical engineering perspective respectively. Moreover, we were dissatisfied with the relevance of any potentially viable questions. For example, unit conversions simply give values to convert without relating them to physical objects that students can visualize. These issues led us to create a new set of energy literacy questions.

Using WeBWork, we created 38 energy literacy-focused word problems spread across six assignments [29]. The question topics ranged in difficulty; early assignments focused on unit conversions, while later assignments incorporated numerous topics into one question, such as efficiency, emissions, costs, and material use. Most questions follow a scaffolding structure in which students must correctly answer the first part of a question before later sections are available. All questions have unlimited attempts and incorporate random variables to encourage collaboration without cheating. After the assignment due date, full solutions are released, allowing students to see where mistakes occurred and ask questions about the solution process.

Specific importance was placed in relating the question back to something that the students can personally connect with. For example, in one of the early questions we develop a scenario where a family sets up a clothesline to save electricity (see the Appendix for the full question). Based on a clothes dryer specification, students calculate how much energy they saved, how much these savings would count toward their total electricity usage, and how much carbon dioxide (CO_2) is saved from being produced. When this is contrasted to simply asking students to calculate carbon dioxide emissions based on an arbitrary electricity use, they build skills on understanding the scale of their own energy flow.

In later questions, we build on topic relevance and highlight data sources for the problems. Directly linking data sources in the question allow students to see where engineers and researchers collect data, investigate the organizations that publish energy system related data, and verify the energy values given in problem statements. Government agencies such as the Canada Energy Regulator [30], the US Energy Information Administration [31], and the United States Environmental Protection Agency [32] are directly linked for emission rates, energy demand, and electricity target data. In addition, specific project pages such as the Site C hydroelectric facility [33] and the Bruce Nuclear Generation Stations [34] are directly linked, allowing students to see what information is freely available about individual facilities. Providing students with the opportunity to see where problem parameter values are being sourced encourages data investigation and builds skills to understand the physical scale of the energy system.

Data Collection

The SFU SEE program requires all undergraduate students to complete a course titled "Energy, Environment, and Society" [35]. In this course, students explore fundamental energy challenges facing society through open discussions, assignments, quizzes, and a course project. This first-year course serves as a foundational component which subsequent classes build upon to produce qualified graduates for energy engineering professions. The course requires no pre-requisites other than what is needed to apply for the program (English 12, Physics 12, Pre-Calculus 12, and Calculus 12) [36]. Therefore, we can expect most of the students enrolled in this course to have minimal to no formal dedicated energy literacy education.

Two different cohorts of students were used as the control and treatment groups to measure the effect of implementing online energy literacy research questions. The fall 2020 SEE cohort is the control group, while the fall 2021 cohort is the treatment. In both groups, the Energy, Environment and Society course is taken by the majority of the students during their first semester in the SEE department. The only major change in curriculum between cohorts is the addition of online assignment questions to the treatment group. It should be noted that the fall 2020 cohort (control) was offered remotely due to the Covid-19 pandemic, while the fall 2021 cohort (treatment) was subject to in-person learning, though with masks and distancing due to the ongoing impacts of Covid-19. Curriculum changes prior to the fall 2020 class meant older cohorts where in-person learning occurred could not be used as the control group.

In the Energy, Environment, and Society course, students complete an energy chain assignment approximately two-thirds way through the term. To summarize the assignment (attached in the Appendix) the students are required to create two energy chains to calculate the scale of energy flow needed to carry out a household activity. One energy chain will follow an electrical flow of energy, while the other will follow a non-electrical flow of energy. For example, boiling a pot of water can be done through an electrical or gas stove. Additionally, the students submit a reflection paragraph comparing the two energy chains. Selecting this assignment as the benchmark for mark comparison is suitable, as it encompasses numerous topics that fit our original definition of energy literacy. The assignment also did not change significantly between cohorts.

Each student's energy chain assignment was individually reviewed to identify where errors occurred. Error classifications are binary, meaning that we only recorded if an error was made and not the severity of the error. Within each assignment we record if an error was made in identifying an energy conversion technology, identifying an energy carrier, performing an efficiency calculation, and if the unit conversion calculations were incorrect. Moreover, if it was evident that the student was conceptually confusing power and energy in the reflection piece, we recorded an additional error. This conceptual error was chosen as anecdotally this has been a prevalent error in previous classes.

Data was also collected on each student's given assignment grade and prerequisite high school grades. Although these metrics can help to find a correlation between the effects of our treatment, caution is needed as we cannot control for marker variance. Each cohort had different teaching assistants who graded assignments, while each student had different teachers who assigned the final high school marks. Therefore, we do not have a reference point on how to assess these results. Nevertheless, these values can be helpful in identifying trends.

Results

Shown below in Table 1 is the received marks for each category in the energy chain assignment, as well as the final mark. The final column shows the difference in marks between the control and treatment year. Conversely to what we expected, the control group received better marks in every category when compared to the treatment year. However, this isn't entirely surprising as multiple variables exist that bias the results. Notably, the control and reference groups were subject to different learning environments (remote vs. in-person) and had different teaching assistants marking the assignments. Furthermore, the small sample size results in an underpowered study which can lead to inconclusive results. Finally, while the difference in final marks may seem significant (~8%), this represents less then one letter grade difference. The marking is done following a pre-defined rubric, where each of the three categories can only be one of five possible marks. If a student is deducted one mark in the rubric, they loose roughly 9% of the total, so an 8% difference in the average grade is not very significant between two such small sample groups.

Table 1: Received Assignment Marks

	Control (n=27)		Treatment (n=25)		
Category	**Mean (%)**	**Std. Deviation (%)**	**Mean (%)**	**Std. Deviation (%)**	**Difference (%)**
Electric Energy Chain	75.59	24.79	65.60	21.23	7.20
Non-Electric Energy Chain	78.45	24.35	72.80	20.72	13.22
Reflection	62.71	19.33	60.80	26.13	3.05
Total	71.65	21.65	66.05	16.93	7.82

Comparing the number of errors recorded between each group, displayed in Table 2, shows our intervention has no consistent effects. If the student made an error, they are assigned a value of 1 in that category, else they receive a score of zero. Most notably, we see a 100% increase in the number of conceptual errors made in understanding the difference between energy and power. However, many of the same uncertainties that existed in Table 1 are present here, such as the different learning environment and small sample sizes. Therefore, just looking at the percentage difference between the two groups does not necessary correlate to conclusive reductions or improvements in errors made.

Table 2: Errors Recorded

		Control (n=27)		Treatment (n=25)		
Category	Type	Mean	Std. Deviation	Mean	Std. Deviation	Difference (%)
Electric Energy Chain	Conversion	0.26	0.45	0.16	0.37	38.46
	Efficiency	0.22	0.42	0.32	0.48	-45.45
	Energy Carrier	0.63	0.49	0.60	0.50	4.76
	Calculations	0.59	0.50	0.68	0.48	-15.25
Non-Electric Energy Chain	Conversion	0.33	0.48	0.36	0.49	-9.09
	Efficiency	0.26	0.45	0.40	0.50	-53.85
	Energy Carrier	0.48	0.51	0.56	0.51	-16.67
	Calculation	0.52	0.51	0.64	0.49	-23.08
Conceptual	Energy vs. Power	0.22	0.42	0.44	0.51	-100.00

To investigate statistical differences between the treatment and control group, we compare average errors using linear regression, controlling for high school grades (shown in the appendix). Regression results were unable to detect any statistically significant differences at the 95% confidence level for any of the categories. Given the null finding, we do not present results here.

Conclusions

Increasing energy literacy in undergraduate STEM education is imperative to produce graduates who can positively contribute to climate change solutions. We study how treating a cohort of first-year engineering undergraduate students with online energy literacy word problems affects their conceptual understanding of the topic. To measure improvements, we analyze the errors made and the marks received in an energy chain assignment given to a control and treatment cohort of students. The results show that there are no statistically significant improvements or reductions in the students understanding of energy literacy through the addition of online problem sets. However, given the small sample size, and inability to control for learning environments, this is not a surprising result.

While no statistically significant findings are found, this does not mean our study is irrelevant. We discuss and implement numerous methods to improve student engagement which can be implemented into course designs for any subject. Moreover, utilizing WeBWork to conduct our study, we are introducing new researchers and instructors to a versatile open-source learning system where they can replicate our study or develop their own.

Future Work

Although our results did not show measurable improvements in student understanding of energy literacy, we have identified numerous areas to improve upon this study. This includes adding gamification mechanics, further increasing the diversity and relevance of problem sets, and developing an energy literacy concept inventory. These topics are individually discussed below. However, more generally, our study highlights the serious lack of dedicated research focused on energy literacy education. There are papers and studies investigating education in other STEM topic areas (such as force topics in physics or graphical communication in engineering), yet this research is not replicated for energy literacy. This literature gap is especially concerning given the importance climate change solutions will have in the future.

Our study serves as a starting point to develop a robust catalog of energy literacy problems, with numerous improvements and complementary material pathways available. The questions developed in this study are based on our experiences of where we see the greatest challenges in building energy literacy skills. Having other industry and academic experts review, modify, and add to the problem sets should be done to ensure that we are covering a sufficient breadth of topics. Moreover, we can modify a subset of our problems to further improve student engagement. For example, instead of supplying the power rating of a drying machine in the attached appendix question, students can look up their own dryer machine and input the wattage, or upload a picture of the rating sticker and use a machine learning algorithm to extract the wattage. This value is then compared against an acceptable range coded in the question. Having students solve questions where initial conditions are dictated by their experiences builds on problem relevance. Finally, WeBWork's gamification mechanics can be implemented to add leveling and badging systems to help further improve student engagement.

Developing an energy literacy concept inventory is imperative to understand effective teaching methodologies for this topic area. Although our study introduces questions to reinforce topics of energy literacy, it does not identify what misconceptions about these topics exist and if introducing online problem sets helped correct these misconceptions. An effective concept inventory requires significant time and effort investment from multiple stakeholders to ensure proper material coverage. Without an energy literacy concept inventory, it is difficult to assess what teaching methods are most effective in improving a student's conceptual understanding of a topic; a skill that is imperative in climate change research.

References

[1] “Energy Literacy: Essential Principles for Energy Education,” *Energy.gov*. https://www.energy.gov/eere/education/energy-literacy-essential-principles-energy-education (accessed Nov. 07, 2021).

[2] S. Singer and K. A. Smith, “Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering,” *Journal of Engineering Education*, vol. 102, no. 4, pp. 468–471, 2013, doi: 10.1002/jee.20030.

[3] A. Struyf, H. De Loof, J. Boeve-de Pauw, and P. Van Petegem, “Students’ engagement in different STEM learning environments: integrated STEM education as promising practice?,” *International Journal of Science Education*, vol. 41, no. 10, pp. 1387–1407, Jul. 2019, doi: 10.1080/09500693.2019.1607983.

[4] “WEF EGW Whitepaper.pdf.” Accessed: Dec. 19, 2021. [Online]. Available: https://www3.weforum.org/docs/WEF_EGW_Whitepaper.pdf

[5] L. R. Murillo-Zamorano, J. Á. López Sánchez, A. L. Godoy-Caballero, and C. Bueno Muñoz, “Gamification and active learning in higher education: is it possible to match digital society, academia and students’ interests?,” *International Journal of Educational Technology in Higher Education*, vol. 18, no. 1, p. 15, Mar. 2021, doi: 10.1186/s41239-021-00249-y.

[6] G. Goehle, “Gamification and Web-based Homework,” *PRIMUS*, vol. 23, no. 3, pp. 234–246, Mar. 2013, doi: 10.1080/10511970.2012.736451.

[7] J. D. Coleman, “Engaging undergraduate students in a co-curricular digital badging platform,” *Educ Inf Technol*, vol. 23, no. 1, pp. 211–224, Jan. 2018, doi: 10.1007/s10639-017-9595-0.

[8] K. L. Carey and J. E. Stefaniak, “An exploration of the utility of digital badging in higher education settings,” *Education Tech Research Dev*, vol. 66, no. 5, pp. 1211–1229, Oct. 2018, doi: 10.1007/s11423-018-9602-1.

[9] M. Jafri and L. Guo, “Mathematics Education Students’ Experiences during Lockdown: Managing Collaboration in eLearning,” *Education Sciences*, vol. 11, no. 4, Accessed: Dec. 19, 2021. [Online]. Available: https://www.proquest.com/docview/2531386716?parentSessionId=llSZGNvmCLMBJH5NbhfUeTOskepQZYeZfpkmwHmCUDs%3D&pq-origsite=primo&accountid=13800

[10] L. Bowman-Perrott, H. Davis, K. Vannest, L. Williams, C. Greenwood, and R. Parker, “Academic Benefits of Peer Tutoring: A Meta-Analytic Review of Single-Case Research,” *School Psychology Review*, vol. 42, no. 1, pp. 39–55, Mar. 2013, doi: 10.1080/02796015.2013.12087490.

[11] C. S. C. Asterhan and B. B. Schwarz, “Argumentation and Explanation in Conceptual Change: Indications From Protocol Analyses of Peer-to-Peer Dialog,” *Cognitive Science*, vol. 33, no. 3, pp. 374–400, 2009, doi: 10.1111/j.1551-6709.2009.01017.x.

[12] C. Howard, B. Di Eugenio, P. Jordan, and S. Katz, “Exploring Initiative as a Signal of Knowledge Co-Construction During Collaborative Problem Solving,” *Cognitive Science*, vol. 41, no. 6, pp. 1422–1449, 2017, doi: 10.1111/cogs.12415.

[13] U. C. Okolie, S. Mlanga, D. O. Oyerinde, N. O. Olaniyi, and M. E. Chucks, “Collaborative learning and student engagement in practical skills acquisition,” *Innovations in Education and Teaching International*, vol. 0, no. 0, pp. 1–10, May 2021, doi: 10.1080/14703297.2021.1929395.

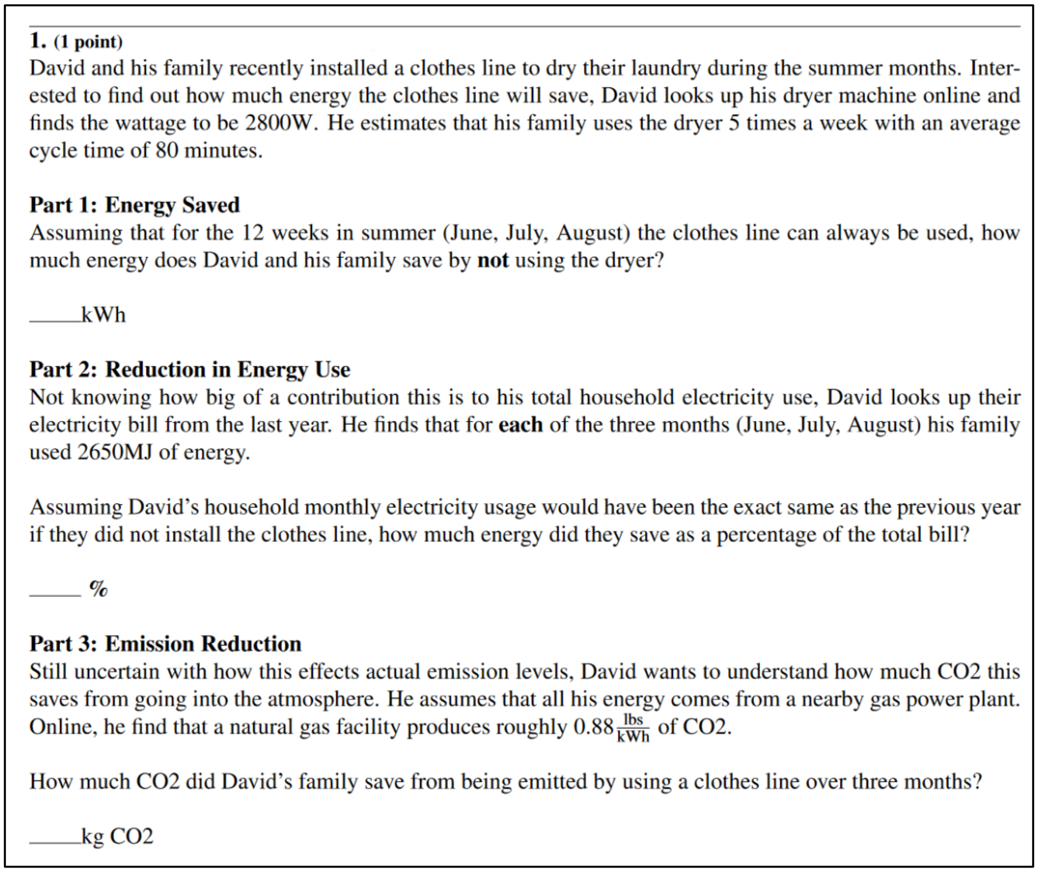
[14] M. Brimble, “Why Students Cheat: An Exploration of the Motivators of Student Academic Dishonesty in Higher Education,” in *Handbook of Academic Integrity*, T. Bretag, Ed. Singapore: Springer, 2016, pp. 365–382. doi: 10.1007/978-981-287-098-8_58.

[15] M. Marchisio, A. Barana, M. Fioravera, S. Rabellino, and A. Conte, “A Model of Formative Automatic Assessment and Interactive Feedback for STEM,” in *2018 IEEE 42nd Annual Computer Software and*

Applications Conference (COMPSAC), Jul. 2018, vol. 01, pp. 1016–1025. doi: 10.1109/COMPSAC.2018.00178.
[16] G. M. N. Isabwe, F. Reichert, and M. Carlsen, “Rethinking practices of assessment for learning: Tablet technology supported assessment for learning mathematics,” in *Proceedings of 2013 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)*, Aug. 2013, pp. 155–159. doi: 10.1109/TALE.2013.6654419.
[17] H. De Loof, A. Struyf, J. Boeve-de Pauw, and P. Van Petegem, “Teachers’ Motivating Style and Students’ Motivation and Engagement in STEM: the Relationship Between Three Key Educational Concepts,” *Res Sci Educ*, vol. 51, no. 1, pp. 109–127, Sep. 2021, doi: 10.1007/s11165-019-9830-3.
[18] C. J. Adams, “A Constructively Aligned First-Year Laboratory Course,” *J. Chem. Educ.*, vol. 97, no. 7, pp. 1863–1873, Jul. 2020, doi: 10.1021/acs.jchemed.0c00166.
[19] L. Thibaut *et al.*, “Integrated STEM Education: A Systematic Review of Instructional Practices in Secondary Education,” *European Journal of STEM Education*, vol. 3, no. 1, p. 02, May 2018, doi: 10.20897/ejsteme/85525.
[20] L. P. McGinness and C. M. Savage, “Developing an action concept inventory,” *Phys. Rev. Phys. Educ. Res.*, vol. 12, no. 1, p. 010133, May 2016, doi: 10.1103/PhysRevPhysEducRes.12.010133.
[21] J. T. Laverty and M. D. Caballero, “Analysis of the most common concept inventories in physics: What are we assessing?,” *Phys. Rev. Phys. Educ. Res.*, vol. 14, no. 1, p. 010123, Apr. 2018, doi: 10.1103/PhysRevPhysEducRes.14.010123.
[22] A. Madsen, S. B. McKagan, and E. C. Sayre, “Best Practices for Administering Concept Inventories,” *The Physics Teacher*, vol. 55, no. 9, pp. 530–536, Dec. 2017, doi: 10.1119/1.5011826.
[23] M. Prince, M. Vigeant, and K. Nottis, “Development of the Heat and Energy Concept Inventory: Preliminary Results on the Prevalence and Persistence of Engineering Students’ Misconceptions,” *Journal of Engineering Education*, vol. 101, no. 3, pp. 412–438, 2012, doi: 10.1002/j.2168-9830.2012.tb00056.x.
[24] F. Önder, “Development and validation of the photoelectric effect concept inventory,” *European Journal of Physics*, vol. 37, p. 055709, Sep. 2016, doi: 10.1088/0143-0807/37/5/055709.
[25] K. Nabutola, H. Steinhauer, S. Nozaki, N. Study, and M. Sadowski, “Engineering Graphics Concept Inventory: Instrument Development and Item Selection,” Jun. 2018. doi: 10.4995/HEAD18.2018.8196.
[26] N. Erceg, I. Aviani, K. Grlaš, M. Karuza, and V. Mešić, “Development of the kinetic molecular theory of liquids concept inventory: preliminary results on university students’ misconceptions,” *Eur. J. Phys.*, vol. 40, no. 2, p. 025704, Feb. 2019, doi: 10.1088/1361-6404/aaff36.
[27] “Welcome to WeBWorK.” https://webwork.maa.org/ (accessed Dec. 16, 2021).
[28] *WeBWorK Open Problem Library*. WeBWorK -- Open Source Online Homework System, 2021. Accessed: Dec. 16, 2021. [Online]. Available: https://github.com/openwebwork/webwork-open-problem-library
[29] *WeBWorK SFU SEE 110 Pull Request*. WeBWorK -- Open Source Online Homework System, 2022. Accessed: Feb. 22, 2022. [Online]. Available: https://github.com/openwebwork/webwork-open-problem-library
[30] C. E. R. Government of Canada, “NEB – Canada Energy Regulator,” Apr. 01, 2021. https://www.cer-rec.gc.ca/en/index.html (accessed Dec. 27, 2021).
[31] “Homepage - U.S. Energy Information Administration (EIA).” https://www.eia.gov/index.php (accessed Dec. 27, 2021).
[32] “U.S. Environmental Protection Agency | US EPA.” https://www.epa.gov/ (accessed Dec. 27, 2021).
[33] “Project Overview | Site C.” https://sitecproject.com/about-site-c/project-overview (accessed Dec. 27, 2021).

[34] C. N. Safety Commission, “Bruce A and B Nuclear Generating Stations,” Feb. 03, 2014. https://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/bruce-nuclear-generating-station/index.cfm (accessed Dec. 27, 2021).
[35] “Sustainable Energy Engineering - Spring Calendar - Simon Fraser University.” https://www.sfu.ca/students/calendar/2020/spring/courses/see.html (accessed Nov. 07, 2021).
[36] “Sustainable Energy Engineering - Undergraduate Admission - Simon Fraser University.” https://www.sfu.ca/students/admission/admission-requirements/canadian-highschool/bc-yukon/sustainable-energy-engineering.html (accessed Feb. 22, 2022).

Appendix



1. **(1 point)**
David and his family recently installed a clothes line to dry their laundry during the summer months. Interested to find out how much energy the clothes line will save, David looks up his dryer machine online and finds the wattage to be 2800W. He estimates that his family uses the dryer 5 times a week with an average cycle time of 80 minutes.

Part 1: Energy Saved
Assuming that for the 12 weeks in summer (June, July, August) the clothes line can always be used, how much energy does David and his family save by **not** using the dryer?

_____kWh

Part 2: Reduction in Energy Use
Not knowing how big of a contribution this is to his total household electricity use, David looks up their electricity bill from the last year. He finds that for **each** of the three months (June, July, August) his family used 2650MJ of energy.

Assuming David's household monthly electricity usage would have been the exact same as the previous year if they did not install the clothes line, how much energy did they save as a percentage of the total bill?

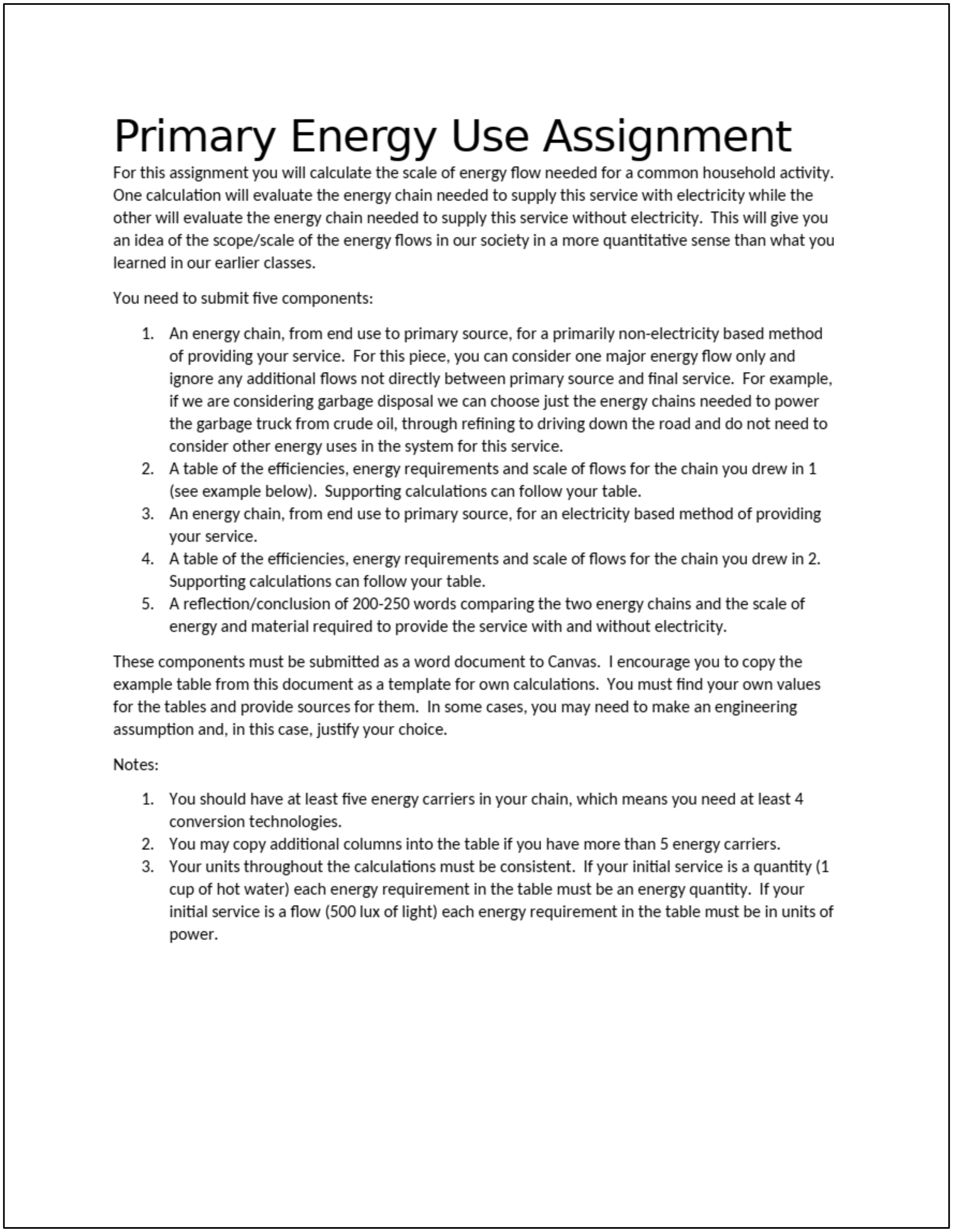
_____ %

Part 3: Emission Reduction
Still uncertain with how this effects actual emission levels, David wants to understand how much CO2 this saves from going into the atmosphere. He assumes that all his energy comes from a nearby gas power plant. Online, he find that a natural gas facility produces roughly $0.88\frac{\text{lbs}}{\text{kWh}}$ of CO2.

How much CO2 did David's family save from being emitted by using a clothes line over three months?

_____kg CO2

Figure 1: Sample WeBWork Question



Primary Energy Use Assignment

For this assignment you will calculate the scale of energy flow needed for a common household activity. One calculation will evaluate the energy chain needed to supply this service with electricity while the other will evaluate the energy chain needed to supply this service without electricity. This will give you an idea of the scope/scale of the energy flows in our society in a more quantitative sense than what you learned in our earlier classes.

You need to submit five components:

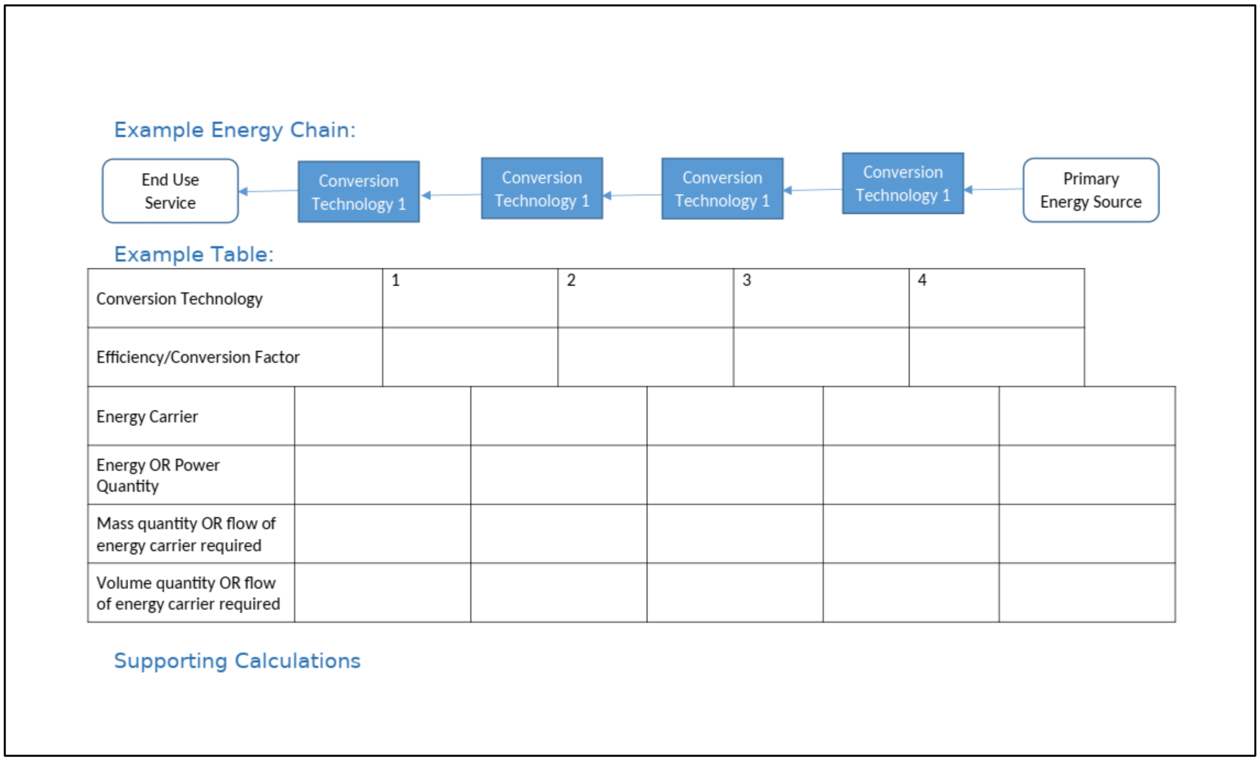
1. An energy chain, from end use to primary source, for a primarily non-electricity based method of providing your service. For this piece, you can consider one major energy flow only and ignore any additional flows not directly between primary source and final service. For example, if we are considering garbage disposal we can choose just the energy chains needed to power the garbage truck from crude oil, through refining to driving down the road and do not need to consider other energy uses in the system for this service.
2. A table of the efficiencies, energy requirements and scale of flows for the chain you drew in 1 (see example below). Supporting calculations can follow your table.
3. An energy chain, from end use to primary source, for an electricity based method of providing your service.
4. A table of the efficiencies, energy requirements and scale of flows for the chain you drew in 2. Supporting calculations can follow your table.
5. A reflection/conclusion of 200-250 words comparing the two energy chains and the scale of energy and material required to provide the service with and without electricity.

These components must be submitted as a word document to Canvas. I encourage you to copy the example table from this document as a template for own calculations. You must find your own values for the tables and provide sources for them. In some cases, you may need to make an engineering assumption and, in this case, justify your choice.

Notes:

1. You should have at least five energy carriers in your chain, which means you need at least 4 conversion technologies.
2. You may copy additional columns into the table if you have more than 5 energy carriers.
3. Your units throughout the calculations must be consistent. If your initial service is a quantity (1 cup of hot water) each energy requirement in the table must be an energy quantity. If your initial service is a flow (500 lux of light) each energy requirement in the table must be in units of power.

(a)



Example Energy Chain:

Example Table:

Conversion Technology	1	2	3	4	
Efficiency/Conversion Factor					
Energy Carrier					
Energy OR Power Quantity					
Mass quantity OR flow of energy carrier required					
Volume quantity OR flow of energy carrier required					

Supporting Calculations

(b)

Figure 2: Primary Energy Chain Assignment (a) Instructions (b) Template

Table 3: Highschool Marks

	Control (n=27)		Treatment (n=25)		
Class	Mean (%)	Std. Deviation (%)	Mean (%)	Std. Deviation (%)	Difference (%)
Pre-Calculus 12	92.00	5.60	91.80	5.21	0.22
Calculus 12	90.33	8.36	88.38	8.16	2.16
Physics 12	90.74	5.78	89.72	5.88	1.12
English	90.19	5.86	90.16	6.14	0.03