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Understanding the Concept Based Learning of Sustainability Aspects of Energy : A Preliminary Study

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Abstract

Climate change is one of the major problems facing the world today. Many people generally understand that there is a problem with the gradual rise in the temperature of the Earth's atmosphere. Climate change has been caused by several environmental problems arising from greenhouse effect global warming. The impact of these has been found to be distressing not only to the ecosystem, but also to the human community. Tackling this problem will require a diverse and expanded workforce of engineers capable of understanding how to apply fundamental conservation of energy concepts. However, many undergraduate engineering students have significant learning blockages when it comes to understanding these basic concepts related to energy. In this new preliminary study, we attempt to better understand these difficulties through student interviews and surveys. In a future study, we will attempt to alleviate these blockages by having engineers and scientists in the field of climate change talk to students to help them understand that, although the concepts they are being exposed to are daunting, what lies ahead of them is a meaningful life-long learning opportunity to understand and apply these concepts in the modern workplace more deeply. In subsequent studies, the authors intend to improve teaching techniques such as animation to bridge the gap between the more detailed and theoretical concepts and real-life applications.

Introduction

Human activities have indeed had a significant negative impact on the Earth's environment, leading to widespread destruction of natural habitats, pollution, and ultimately, global warming [1]. The scientific consensus is clear that human activities, primarily the burning of fossil fuels and deforestation, have been the primary drivers of climate change over the past few decades. The increased levels of carbon dioxide in the atmosphere, resulting from these activities, have trapped heat and caused global temperatures to rise at an unprecedented rate [3]. Energy and the environment, especially the issue of global warming caused by human-generated greenhouse gases, have become a major global concern. This topic is discussed extensively by world leaders, scientists, policymakers, and the public. The Intergovernmental Panel on Climate Change (IPCC) has been a leading authority on climate change, providing comprehensive assessments of the scientific basis of climate change, its impacts, and future risks. Their reports consistently point to human activities as the primary driver of global warming. The recognition of the urgency of this issue has led to widespread efforts to reduce greenhouse gas emissions and transition to cleaner energy sources [4].

Educating young people about environmental issues is a cornerstone of fostering sustainable practices and a healthier planet. By cultivating ecological awareness from a young age, we can empower future generations to make informed decisions and contribute to positive environmental change. Previous studies and research results were highly significant and align with current understanding of environmental education**.** The correlation between increased scientific knowledge and a greater likelihood of expressing activism is particularly encouraging, as it suggests that effective environmental education can empower students to become active citizens and agents of change [2].

In higher education, the increasing emphasis on sustainability is driven by a multitude of factors: environmental impact, rising energy cost and future workforce needs [5,6]. The cross-disciplinary nature of energy-efficient building design has created many challenges for architecture, engineering and construction instructors. The key challenge in teaching sustainable building design is the complexity of integrating various factors like energy efficiency, material selection, and building orientation, as these concepts can be difficult to convey through traditional methods [7]. The multifaceted nature of this problem makes energy a powerful unifying concept in science education, but this can lead to confusion for students, especially as they progress through different grade levels and subject areas [8].

Although curricula across the globe have strengthened efforts to support teaching energy concepts, most learners struggle to develop a deep understanding of energy. Research focus on the relationship between energy understanding and climate change is timely and critical [9]. Therefore, the objective of this paper is to develop a model of energy and climate change education that can inspire public consciousness and influence environmental behavior which is a valuable contribution to the field.

Analysis

First, we conducted focus group interviews of a senior-level thermodynamics class in order to assess student perceptions, then a thematic analysis was Then, a second survey study was performed on first- and third-year students to assess their perception of climate change. The results of this preliminary analysis will be useful in developing future learning tools.

A. Thematic Study of Senior-Level Class

In order to better understand the students' perspective on Thermodynamics courses, an initial thematic study was conducted. Once the data were collected from the focus groups, a thematic analysis was conducted to look for emerging themes from the student responses [10]. Forty four percent (44 %) of students from a senior-level class were interviewed and responded to the survey asking them four (4) distinct questions:

1. In your opinion, please describe the significance of Thermodynamics as it relates to being an engineer.
2. Describe your experience(s) with the Thermodynamics course(s).
3. Please describe the method of delivery with regard to the course material (whiteboard, text, digital delivery, etc.)
4. Did the professor use tools and supplements to teach the Thermodynamics course(s)?

In total 11 students were interviewed, and the results of these interviews were compiled and presented in Table 1 for Questions 1 and 2 and Table 2 for Questions 3 and 4. These preliminary data will be valuable in helping us design appropriate learning tools going forward. Also, additional data will be collected in Year 1 to further calibrate our understanding of what is needed in the new learning tool. Note that, in these summaries, items highlighted in yellow represent possible areas of student misunderstanding, so these areas will be further probed in subsequent student interviews and surveys.

Table 1. Summary of responses to Questions 1 and 2 of Thematic Analysis (11 respondents).

No.	Question	Responses
1	In your opinion, please describe the significance of thermodynamics as it relates to being an engineer.	• Thermodynamics provides a fundamental foundation for mechanical engineering students. • Thermodynamics inspires further learning (i.e., rocket propulsion fluids) • Thermodynamics and Fluids apply to anything that is not electrically powered and push the physical limit.
1a	How do you see yourself using this material after the course?	• Thermodynamics is useful for Co-Op experiences across different types of work. • Thermodynamics provides a solid foundation for forming a deeper understanding of principles. • Fluid behavior matters and applies across different types of work associated with mechanical engineering. • Thermodynamics is more abstract; unsure how to use it in real-world settings.
1b	From your perspective, what job opportunities exist with regard to fluids and thermodynamics?	• Aerodynamics—working with heat energy. • Aerospace field—almost all aspects of the job use thermodynamics; all theories are adapted for calculations; will the plane fly/melt? • NASA—Thermodynamics and Fluids are useful for making materials (Co-Op/Full-Time); whether you have a degree or not, we all use thermodynamics at work. • Automotive/Motor Sports—optimizing vehicles; cooling flow of fluids, braking systems, fluid exit without interfering with other aspects; power generation. • Military—Fluid behavior matters (flow, hydrostatic pressure). • Biotech—products; helps with understanding loss/shear as product travels through the body; can aid in potency; efficiency • Material Sciences—microwave work; topic of thermodynamics is like a dictionary/encyclopedia; less of a tool, more of a reference. • HVAC—liquid propulsion (fluids); thermodynamics helps with calculations. • Machinery—quench system in heat dissipation; thermodynamics helped with this kind of work. • Thermodynamics can be useful for the non-engineer as well (ex: Hasbro knowing melting points for plastics used on the factory side. • Robotics—only slightly applies.
2	Describe your experience(s) with the thermodynamic courses	• Thermodynamics I and II encourage problem-solving/resilience in solving problems (working through incorrect answers to find the issue). • Course projects aid in student learning/retention of knowledge • Professor plays a pivotal role to shape positive and/or negative student experience.
2a	What did you like about the course?	• Lectures are good; Labs are critical (formulas, tables). • Labs offer more self-application opportunities. • Most mechanical engineering programs offer only Thermodynamics I, so Wentworth students are at an advantage. • Thermodynamics II was difficult but useful; course material has practical applications; not too much homework. • Overviews (agenda of what will be covered) help.
2b	What, if anything, was challenging about the course?	• Ego-driven teaching styles are not effective. • Some professors do not answer questions during class. • Rushing through slides is not helpful for retention of learning. • Final exams are cumulative and require a lot of study time. • Memorizing formulas is challenging.

Table 2. Summary of responses to Questions 3 and 4 of Thematic Analysis (11 respondents).

No.	Question	Response
3	Please describe the method of delivery with regard to the course material (whiteboard text, digital delivery, etc.)	• Writing (Whiteboard)—typically used during lectures. This worked for me and is my preference; I don't like PowerPoint slide lectures, because I don't learn as much. Nothing compares to whiteboard learning; the pace of writing on board can give students time to absorb the material and grasp concepts more effectively. Whiteboard offers a more cogent approach, and it helps the professor model behavior that is beneficial to students. I prefer short lectures; the ideal learning environment has practice problems outside of class. Tablets are useful in place of/in addition to whiteboard, but there are some differences between the two (re: delivery). • Slides (PowerPoint)—Slides give a conceptual view of course material. Reading slides is tough; slides are better as a tool but not the main focus. Slides have everything we need to know, but they often are lacking in terms of explanation; the pace ends up being too fast. Some professors write on the slides during lectures. PowerPoints with writing, or just PowerPoints, were used in lectures. • Social Learning (Bandura, 1977)—Class discussions allow for more than one voice in the classroom. Interacting with other students—I was paired with another student from the class to talk about assignments to explore similar and differing perspectives; Team/Group work; Asking questions during class helps and can help other students who might have the same question. • Course Text/Learning Material on Own—I learn best by teaching myself the material. I was able to find a website that had property tables, and also sought learning from other books related to topics covered in the course. I read the course text ahead of the class on my own and this helped a lot; it is good to learn the material twice (once as individual/student, and again during class). Texts are broad and general
4	Did the professor use tools and supplements to teach the thermodynamics course?	• Thermodynamics I—an "explainer sheet" would be helpful. More practice-oriented supplemental material would be helpful. • Thermodynamics II—no supplemental materials needed. Professors know what we need to know.
4a	If so, please comment on the tools and supplements that you personally found to be most useful as it relates to learning and retaining the course material.	• Engineering Equation Solver (EES)—EES is a good tool but doesn't translate to real-world applications well. • Printed examples help a lot to grasp concepts. • Table packets and diagrams help a lot. • Extra (real life) examples offer an immediate transfer of knowledge. • Tools and supplemental info help to retain the material.

In this section, a summary of observations is provided for each of the questions in Table 1.

Question 1a—Significance of Thermodynamics

One significant response here is that a student noted that "thermodynamics and fluids apply to anything that is not electrically powered." This bias may be due to the queried students being mechanical engineering students. However, in both of these courses—Thermodynamics and Fluid Mechanics—the concept of converting electrical power to mechanical power is definitely addressed. This points to the continual need to educate the students that most real-world problems require highly interdisciplinary skills, as products often involve both mechanical and electrical components. Furthermore, potential solutions to climate change and global warming will certainly require the application of fluid mechanics and thermodynamics to both mechanical and electrical solutions, such as wind turbine designs, solar power, etc.

Question 1b—Use of Thermodynamics

One significant response here is that one student was "unsure how to use it in real-world settings." Again, this points to the need to show students how products, such as wind turbines and solar panels, require knowledge of fluid and thermodynamic principles.

Question 1c—Job Opportunities

One of the most interesting observations pertains to the student response to Question 1b—From your perspective, what job opportunities exist with regard to fluids and thermodynamics? While many different career options were listed, no students listed careers in climate change or addressing global warming, sustainability or resiliency, for example.

Question 2—Describe your experience with the thermodynamic courses.

Here, the students noted how they have used thermodynamics to solve problems and develop resiliency in working through incorrect answers. Also, they noted that "course projects aid in student learning/retention of knowledge," so this reinforces the need for hands-on laboratory and project-based learning, which is a strength of the Wentworth Institute of Technology.

Also, one student noted that the "professor plays a pivotal role to shape positive and/or negative student experience." Here, it is worth noting that, in general, developing strong problem-solving, critical thinking, and teamwork skills in the context of thermofluids, students will be well-prepared for careers in various fields, including renewable energy, sustainable engineering, and environmental engineering.. For example, the design of a new jet engine is not the result of one engineer working for a short period of time. Quite to the contrary, this requires a large team of engineers working for months or even years to reach a final comprehensive solution.

Therefore, it may be important to tell students that these are simply introductory courses and that they should not despair if they have not mastered thermodynamics after one or two semesters of undergraduate education, as these concepts are only fully understood after applying these concepts rigorously over extended periods of time. Even then, seasoned engineers often have to use trial-and-error approaches, coupling idealized theoretical calculations with experimental data to converge on a comprehensive design solution.

By painting the picture in this way, we may be able to encourage, as opposed to discourage, undergraduate mechanical engineers to continue in this much-needed field, allowing them to participate in solutions to real-world problems, such as global warming and climate change.

Question 2a—What did you like about the course?

Once again, students highlighted the critical importance of the hands-on laboratory experience, also noting that "course projects aid in student learning/retention of knowledge." Also, students noted that having two semesters of thermodynamics—MECH 2250 Thermodynamics I and MECH 2750 Thermodynamics II—gave them a competitive advantage in the thermodynamics field, as the second course reinforced their understanding of this material.

Question 2b—What, if anything, was challenging about the course?

Again, the students highlighted the effect of the professor, including negative experiences. Again, this may be due to the difficult conceptual nature of this material. Therefore, professors should reflect on their teaching style, noting the difficulty of learning this material.

Students also noted that memorizing formulas is challenging. Clearly, there are a lot of formulas and numerical data, such as those included in the steam tables, required for solving thermodynamics problems. Here, professors should remind students that even seasoned engineers do not memorize these formulas and data; instead, they use computer programs to solve problems and rely on software databases, such as EES[12], for finding material properties.

Question 3—Method of Delivery

Methods included use of whiteboards, PowerPoint slides, class discussions and individual reading assignments. Students generally preferred the use of whiteboard learning to PowerPoints, as it was easier for them to comprehend. Students also liked in-class discussions, and others did note the importance of reading the material on their own. In general, reading the text material multiple times should be encouraged, as thermodynamics principles can be difficult to comprehend after reading only one time.

Question 4—Use of Tools and Supplements

Students expressed a need for an "explainer sheet" and "more practice-oriented supplemental material."

Question 4a—Preferred Tools and Supplements

In addition to having printed examples and table packets, students pointed to the need for extra (real life) examples, as they "offer an immediate transfer of knowledge." Therefore, professors should consider sharing from their own industry experience, if possible, or from their current research, as it helps students tie theory to real-world more immediately.

B. First-Year and Third-Year Student Surveys

After interviewing and learning from the senior-level student surveys, 88 first-year students and 17 third-year students were surveyed to assess their perspective on climate change topics. Comparing the perspectives of first year and third-year engineering students on climate change can provide valuable insights into how their understanding and attitudes evolve throughout their academic journey and the understanding of third-year engineering students to that of first-year students regarding the causes, impacts, and potential solutions to climate change is a crucial aspect of your research.

Tables 3 and 4 show the analysis of the valuable insights into student responses and identify areas for improvement in teaching and learning. Most students recognize that carbon dioxide is not the only greenhouse gas. Also, there is some level of uncertainty amongst students regarding the contribution of greenhouse gases to global warming, so this points to an area where additional teaching is warranted. On the other hand, over 2/3 of first-year students thought that thermodynamics courses would help them understand the concept of global warming, whereas fewer third-year students shared this perspective. This difference may be due to the third-year students learning that it is a more complex problem to solve and the actual courses are more introductory. This may point to a need to reinforce the need for lifelong learning in this field. Most students do believe that the climate has changed over time and there are consequences to global warming. While a significant percentage of first-year students believe that global warming is just a cycle of climate change, no third-year students shared this view. This may indicate that the thermodynamics courses are helping the students understand the concept of climate change from both a theoretical and practical perspective, allowing them to make a better, more-informed judgement.

Table 3. Summary of 17 third-year student responses. MECH2250, 23 enrollments

Questions	**Third year student response**		
	Yes	**May be**	**No**
Q#1: Do you think global warming will be solved in your lifetime?	**NA**	**58%**	**42%**
Q#2: Is carbon dioxide the only greenhouse gas?	**NA**	**5%**	**92%**
Q#3: Do all greenhouse gases contribute to global warming?	**25%**	**17%**	**58%**
Q#4:Do you think thermodynamics courses can help you understand the concept of global warming?	**42%**	**58%**	**n/a**
Q#5Has the climate changed over time?	**83%**	**17%**	**n/a**
Q#6: Are there consequences of global warming?	**75%**	**25%**	**n/a**

Q#7: Do you think global warming is just a cycle of climate change?	**33%**	**25%**	**42%**

Table 4. Summary of 88 first year students' responses. ENGR1100, 110 enrollments

Questions	**First year student response**		
	Yes	**May be**	**No**
Q#1:Do you think global warming will be solved in your lifetime?	**5%**	**54%**	**41%**
Q#2:Is carbon dioxide the only greenhouse gas?	**1%**	**7%**	**92%**
Q#3:Do all greenhouse gases contribute to global warming?	**28%**	**30%**	**43%**
Q#4:Do you think thermodynamics courses can help you understand the concept of global warming?	**67%**	**32%**	**1%**
Q#5:Has the climate changed over time?	**80%**	**17%**	**2%**
Q#6:Are there consequences of global warming?	**79%**	**18%**	**4%**
Q#7:Do you think global warming is just a cycle of climate change?	**26%**	**41%**	**34%**

Survey responses are shown in Figures 1 and 2. Afterwards, some observations about these responses are summarized.

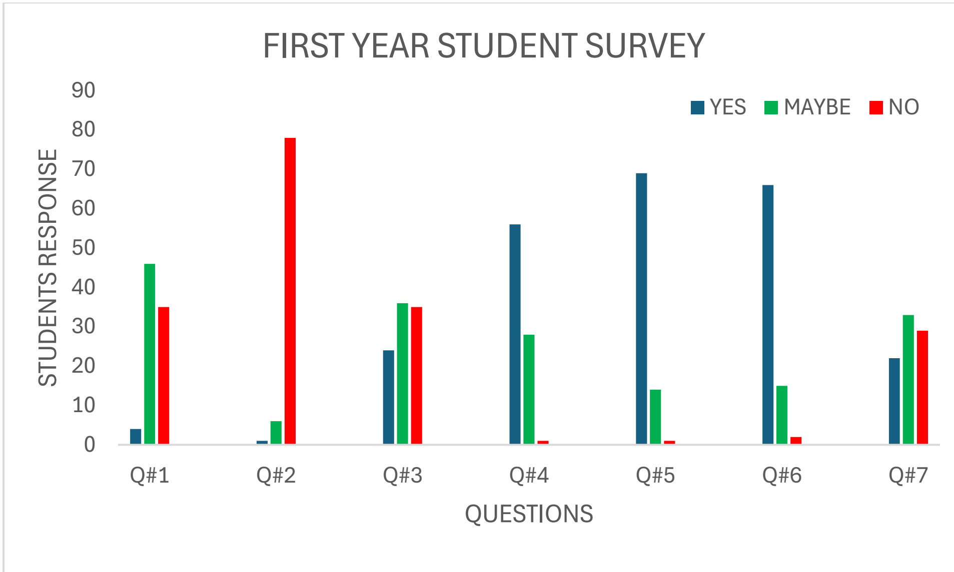

Figure 1. First year student survey

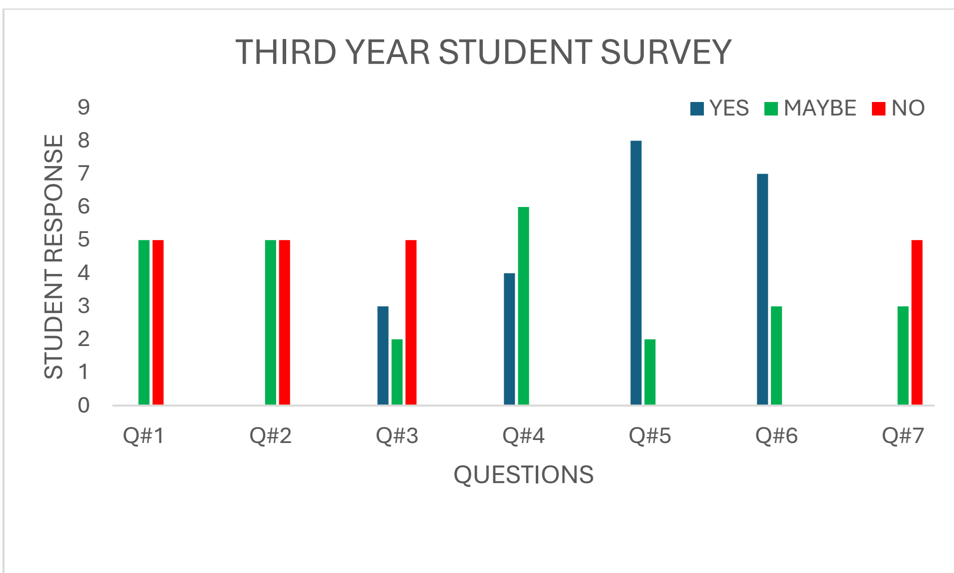

Figure 2. Third year student survey

C. Model of Energy and Climate Change Education

Going forward, the plan is to develop a comprehensive model which links the needs of energy and climate change with thermodynamics education. A preliminary schematic of this model is shown here in Figure 3.

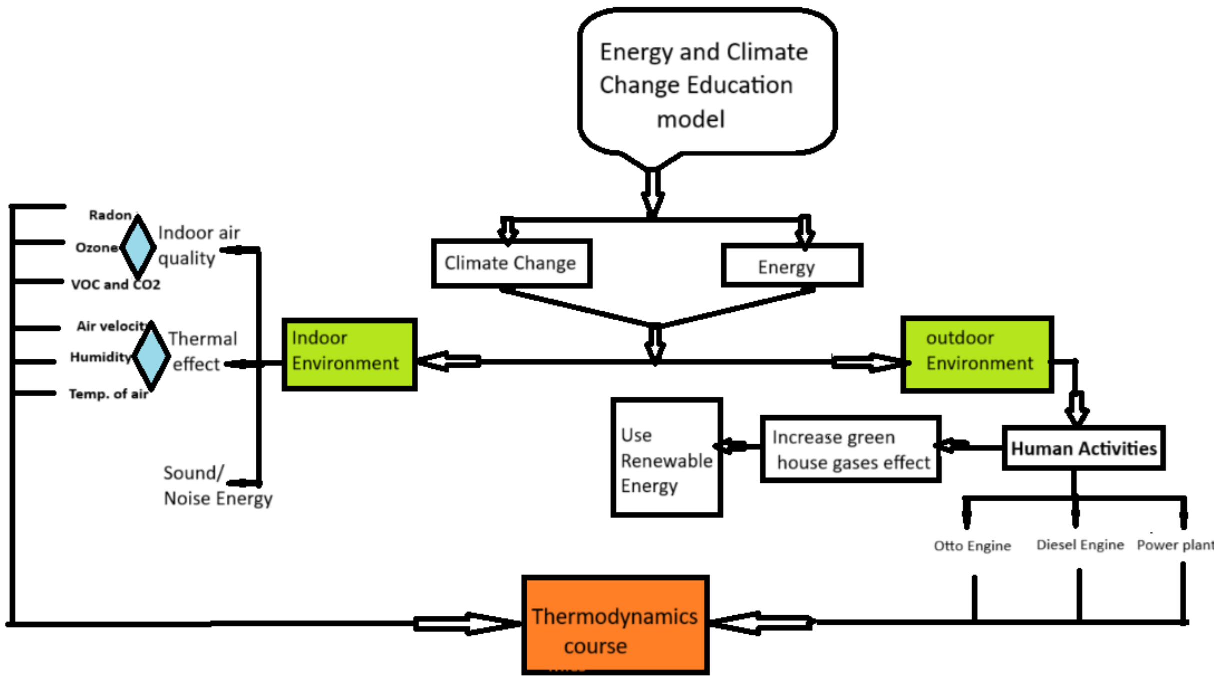

Figure 3. Conceptual energy and climate change education model.

This model is comprehensive in that it considers energy and climate change as they relate to both the indoor and outdoor environments. The various aspects that pertain to the indoor environment, including indoor air quality, and the outdoor environment, including renewable energy and increases in greenhouse gases, define the educational needs for a suitable thermodynamics course curriculum. The developed model highlights the crucial role of thermodynamics in understanding various real-world applications, including thermodynamics principles govern heat transfer and air movement within buildings. Many renewable energy technologies, such as solar thermal, wind power, and geothermal energy, rely on thermodynamic principles for their operation. As we discussed, thermodynamics provides a fundamental framework for understanding the Earth's climate system, the greenhouse effect, and the impacts of human activities on global warming.

By incorporating these real-world applications into elective courses, students can gain a deeper appreciation for the relevance and importance of thermodynamics in addressing contemporary challenges and develop a more holistic understanding of the interconnectedness of science and engineering.

Discussion

This study is focused on investigating whether exposure to specific engineering courses such as thermodynamics enhances students' understanding of climate change concepts. Also, It helps to identify which courses are most effective in developing climate change awareness and knowledge within engineering curricula. On the other hand, comparing first year students and third year students can identify specific areas where third-year students demonstrate a stronger understanding compared to first-year students. This can also reveal knowledge gaps or misconceptions that persist despite exposure to engineering coursework.

Core courses like thermodynamics provide a solid foundation for understanding climate change. The First Law of Thermodynamics, which states that energy can neither be created nor destroyed, is fundamental to understanding the energy balance of the Earth's climate system. The Second Law of Thermodynamics explains the transfer of heat energy and its implications for climate patterns. Furthermore, Thermodynamics principles can be applied to design energy-efficient technologies and systems to reduce greenhouse gas emissions. Thermodynamics can be a challenging subject for many students, even with hands-on experiments. Thermodynamics deals with abstract concepts like energy, heat, work, entropy, and temperature. These concepts can be difficult to visualize and grasp intuitively.. Also, many students may have limited experience with laboratory equipment and techniques, leading to difficulties in conducting experiments. Lab experiments such as Rankine cycle, heat pump and heating-cooling refrigeration system involve multiple components (compressors, turbines, condensers, evaporators) with intricate connections and precise control of operating parameters. These experiments can present significant challenges for students such as intricate setup, Data Acquisition and Analysis. Moreover, limited lab time can make it difficult for students to complete experiments effectively and efficiently. Also, insufficient access to equipment and resources can delay the learning process. Students often face challenges when it comes to analyzing and interpreting experimental data, especially in fields like engineering where data sets can be large and complex. Some strategies to help students overcome these learning barriers include using animations to illustrate complex concepts and utilizing simulation software like MATLAB, Simulink, EES and specialized thermodynamics simulation software can be used to model and simulate various thermodynamic systems to allow students to experiment with different parameters and observe the results [12]. Physical models provide a tangible representation of abstract thermodynamic concepts. Students can interact with the models, manipulate them, and observe their behavior firsthand.

Conclusion

Students who have not taken thermodynamics may still hold misconceptions about global warming. Therefore, conducting simulations to demonstrate the greenhouse effect and climate change and using data analysis tools to explore climate data and trends will help the students to understand the environmental impacts of climate change. By addressing the challenges students face in understanding thermodynamics and implementing effective teaching strategies, we can help them develop a deeper understanding of climate change and its implications. Thermodynamics provides a crucial foundation for understanding climate change and developing effective solutions to address this global challenge. By incorporating climate change considerations into thermodynamics education, we can empower future generations of engineers and scientists to play a vital role in mitigating the impacts of climate change. It is crucial to help students develop a strong foundation in thermodynamics, not only by equipping them with essential engineering skills but also empowering them to contribute to the development and implementation of sustainable solutions to address the challenges of climate change.

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2/20/25

Dear Chair:

Thank you for providing a summary of the reviewer feedback on our paper entitled, "**Understanding Concept-Based Learning of Sustainability Aspects of Energy: A Preliminary Study**" In the attached Response to Reviewer Comments, we attempt to address each of the reviewer's comments with an appropriate response.

Please let us know if you need any additional information.

Thank you in advance for your help with the review process. We are looking forward to presenting this paper at the upcoming conference.

Best regards,

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A reviewer commented on the draft

Comment#1. Page 2, third paragraph: The sentence starting with “The dual nature.....” is missing a verb and therefore incomplete. Please revise.

Response#1: the verb has been added, “The dual nature makes energy a powerful…”

Comment# 2. Page 3, Senior-Level Class: It will be interesting to know what fraction of the senior students responded to the survey. Most, if not all, mechanical engineering students should have taken basic thermodynamics and heat transfer courses.

Response#2: The fraction of senior student was added, “. Forty four percent (44 %) of students from a senior-level class were interviewed and responded …”.

Comment#3: Page 9: Would be good to know the number of students responding. The column charts should preferably have QUESTION as the horizontal axis, and NUMBER OF STUDENTS as the vertical axis. For the NO answer, I recommend choosing red or other distinct color. The colors for YES and NO are very similar in these charts. Also, the number of 3rd year students responding is rather small compared to the 1st year students. It would be good to have a reason for this. One possible reason is that the first course is a core course taken by all engineering students, while the third-year course is for mechanical engineering students only, with much smaller class size.

Response#3: 88 students participated from the first year and 17 students have participated from senior year. For the chart, no. of students is used as the vertical axis, the questions as the horizontal axis, “no” changed to red, “yes” changed to dark blue, and “maybe” changed to green. Regarding the number of students of third year is smaller than 1st year, under Discussion, the answer was added: “ The number of students who have been interviewed from the introductory course is likely larger than the.....”

Comments on Discussion and Conclusion:
These sections should be rewritten, more to reflect the results of the surveys conducted, than to discuss generalities of the difficult nature of the introductory thermodynamics courses. Please avoid repetitive use of words like “many student” and “moreover”. The sentence “…trends will help students to understand …. “, should be rewritten without the “to”.

Response: the discussion and conclusion have been rewritten considering reviewer comments, Removing the repetitive "many student" and "moreover"

A reviewer commented on the draft

This paper discusses the importance of students' awareness of global warming and climate change in fundamental core engineering courses such as thermodynamics. Given the significance of climate change as a real-world challenge for engineers today, this is a highly relevant and interesting study. However, I have several suggestions for improvement:
Comment# 1: It would be helpful to provide details on the course number, enrollment, and the number of participants in the study for all presented data.

Response#1: the details regarding the course number, enrollment,... have been added.

Comment#2: How was the developed model implemented in the course material, considering the already heavy teaching load of fundamental thermodynamics concepts?

Response#2: how the developed model implemented in the course material was explained under the second paragraph under the model, "The developed model highlights the crucial role of thermodynamics in understanding various real-world applications, including thermodynamics principles govern heat transfer and air movement within buildings. Many renewable energy technologies, such as solar thermal, wind power, and geothermal energy……."

Comment#3: What types of hands-on projects were used in these classes? A clearer explanation of their connection to global warming and climate change awareness would be beneficial. Additionally, it would be helpful to discuss the course content in more detail, particularly the types of hands-on labs offered in the thermodynamics program.

Response#3: under "Discussion", it has been explained the types of hands-on experiments and their connection to global warming, "The professor demonstrates to the students the impact of these experiments on climate change, using the Rankine cycle as an example. The Rankine cycle represents a fundamental thermodynamic model…."

Comment#4: For a senior-level course, only 11 students were interviewed. How conclusive are the results presented given this sample size?

Response#4: Given the low response rate from the initial pool of senior-level students (only 11 participants), the research scope was expanded to include interviews with students from first year and third-year courses. This broader sampling strategy aimed to gather a more comprehensive understanding of student perspectives on thermodynamics principles and their connection to climate change across different stages of engineering education.

Comment#5: In Part C, question 1a is repeated twice. Please revise this section.

Response#5: it has been fixed from 1a to 1b

Comment#6: There are some discontinuities between the topics discussed in the paper, such as the instructor's pivotal role in students' learning experiences, the value of teamwork, the challenging nature of the course material over time, and students' future careers in climate change and global warming fields. A more cohesive discussion would strengthen the paper.

Response#6: the discussion has been added under "C. **Thematic Study Response Summary"** regarding the discontinuities between instructor's pivotal role,.....and students' future careers in climate, "Also, one student noted that the "professor plays a pivotal role to shape positive and/or negative student experience." Here, it is worth noting that, in general, developing strong problem-solving, critical thinking, and teamwork skills in the context of thermodynamics, students will be well-prepared for careers in various fields, including renewable energy…..".

Comment#7: A reference is missing on page 8 for the software mentioned.

Response#7: the reference has been added.

Comment#8: In Section D, seven questions in the table are not numbered, making it unclear which question corresponds to each figure. Please clarify this.

Response#8: the seven questions have been numerated.

Comment#9: Tables 3 and 4 need to include the course number, enrollment, and number of responses for better clarity.

Response#9: it has been fixed, and the course number, enrollment, and number of responses have been added to the tables 3 and 4.

Comment#10: the paper mentions improving teaching techniques by including animations in the course syllabus, but there is no discussion on how this was implemented. What specific simulations were used, and how did they contribute to student learning?

Response#10: the teaching techniques to improve teaching have been added under discussion, "Some strategies to help students overcome these learning barriers include using animations to illustrate complex concepts and utilizing simulation software like MATLAB, Simulink, EES and specialized thermodynamics….".

Overall, this is a valuable study, but addressing these concerns would enhance its clarity and impact of your work.
Thank you!

A reviewer commented on the draft

The survey data between the first- and third-year students is especially illuminating to see their confidence in their major helping them to solve global problems dip. It's telling that they understand the material better and now know how hard of a problem it is! Excellent ideas for better shaping thermo courses to help students better see the big picture.

A reviewer commented on the draft

Thank you very much for your submission to the Mechanical Engineering Division. Your time and expertise are greatly appreciated. Your paper reads well and will be of interest to members of the ME Division, especially those teaching Thermodynamics. Your data from interviewing the senior students about Thermodynamics is excellent and will be of interest to all engineering educators as much of the feedback provides a basis for making Thermodynamics courses more of an active learning environment. Your data from surveying the 1st and 3rd year students about climate change is good and of interest. The confusion with your paper is that there needs to be more information as to why you have put these two sets of data together. Please explain more about the surveys on climate change and provide the questions before the charts, not afterwards. It was very confusing to just dive into the charts after reading about the results from Thermo students. There was no segue way from one data set to the other and hence your paper reads as two research projects slapped together to make a paper. Please provide more details about the model and how the previously mentioned data resulted in your model design decisions. Looking forward to these explanations in your revised draft.

Response: more explanation has been added regarding "the use of two sets of data together" and "explaining more about the surveys on climate change", the questions have been moved before the charts. The two datasets were collected to investigate student understanding of thermodynamics.

- **The first dataset** focused on general understanding of core thermodynamics concepts.
- **The second dataset** expanded the scope to explore the connection between these fundamental concepts and their implications for climate change.