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World Energy in Engineering Design

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World Energy in Engineering Design

Abstract

As engineering students consider the economic, social, political and ethical aspects of design, they are often treated as compulsory aspects that must be checked off a list as they dive deeper into the technical aspects of design. Getting students to appreciate the real-world societal relevance as an integral part of design is often challenging. The World Energy Exercise, which integrates an interactive and state-of-the-art computer simulation with a role-playing exercise, opens a social and active learning pathway, which helps students connect their engineering designs with real-world societal relevance. The exercise enables students to control various energy related policy levers that impact global climate change. One lever in the exercise, the carbon pricing policy, also plays a major role in the students' regenerative steam power cycle design. Carbon pricing is a real-world consideration, with policies currently enacted and/or under consideration at state, regional, and national levels. Incorporating the World Energy Exercise (created by Climate Interactive and the UMass Lowell Climate Change Initiative) into the senior level thermal fluids systems design course provided many students with an increased understanding and motivation to address the complex social, political and economical issues related to their technical design. The exercise did not change the students' technical design parameters such as thermal efficiency, but it provided students with an increased appreciation of the societal relevance of this parameter. Student reflections reveal that the exercise deepened their understanding of the nontechnical issues both in the design and in life in general.

Introduction

Efficiency is a broad topic, which students analyze throughout an undergraduate engineering education. In the context of engineering, more efficient is always better, and many students will enter the workforce to play a role in designing a more efficient device or process. How does a more efficient machine affect humankind, specifically the thermal efficiency of a vapor power cycle? One would hope that students of any discipline would be able to articulate how reducing the combustion of fossil fuels would impact society, yet with the current design of engineering curricula, anthropogenic (human-caused) climate change may not have been specifically addressed. Climate change is considered by many to be a defining issue of our time and, throughout our students' careers and lifetimes, its importance will only increase. Since the onset of the Industrial Revolution, human activities, and primarily our use of fossil fuels, has increased the concentration of carbon dioxide, a greenhouse, or heat-trapping, gas in the atmosphere by more than 40%[1]. On our current emissions trajectory, carbon dioxide concentrations may triple compared to pre-industrial levels by 2100. How this increase is going to impact climates across the globe and what can be done to mitigate this change are very challenging questions – perhaps too complex and too broad to be addressed in an engineering design course. Yet, engineers must play a vital role in addressing the complex challenge of anthropogenic climate change. Actively engaging students in thinking and talking about climate change mitigation in their engineering courses can have a profound impact in motivating them to be a part of the solution. In addition, engaging students with the topic of global climate change in an engineering context also supports many student outcomes currently established in *ABET's Criteria for Accrediting Engineering*

Programs.[2] For example, outcomes h-j, listed below are specifically supported by the World Energy Exercise.

> (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
> (i) a recognition of the need for, and an ability to engage in life-long learning
> (j) a knowledge of contemporary issues

Dedicating a small segment of an engineering course or design project that serves as a mechanism to address the topic of global climate change as an integral part of the design, while facilitating the attainment of several student learning outcomes may seem overly ambitious, however the World Energy Exercise enabled us to achieve this goal, as it was integrated into an otherwise ordinary design project.

The Design Project

In the senior level engineering course, Design of Thermal Fluid Systems, a required course for mechanical engineering students at the University of Massachusetts Lowell, students use the knowledge and skills they acquired in thermodynamics, fluid dynamics and heat transfer in several open-ended mini-design problems. The assignment, *Power Plant Design in the Age of a Carbon Fe*e requires student groups to optimize the design of a vapor power cycle using various techniques to improve cycle efficiency. Student designs must generate a required amount of power with the maximum possible profit and incorporate at least one feedwater heater. The energy sources available to fuel the power plant are coal, oil, natural gas, and a solar concentrator. Each fuel has an associated dollar cost, heating value, and combustion efficiency, and each fuel emits a known amount of carbon dioxide. Students are provided a hypothetical "carbon price" or fee which significantly offsets the profits of the polluting fuels.

When the *Power Plant Design in the Age of a Carbon Fee* project was first introduced, the World Energy Exercise was not conducted. The large class of approximately 120 students received several lectures reviewing steam power cycles and measures to increase cycle thermal efficiency. They also learned to use *X Steam, Thermodynamic Properties of Water and Steam*, which enables students to utilize MATLAB to quickly obtain steam property data without interpolation or tedious table lookups.[3] This project, as it was originally introduced, was a vapor power cycle from thermo class, with the added dimension of a financial analysis and the additional challenge of creating a MATLAB computer code to conduct a parametric analysis. Although this project was somewhat successful at integrating real-world social, political and economic issues into design, the students remained heavily focused on coding and number crunching. It seemed as if a computer code could solve the complex problem and the carbon fee was just another number to input into the code. The students were not asked if they understood or agreed with the proposed fee, they just programmed it in as negative cash flow and had obvious pride in producing "correct" results. The obvious correct (non controversial) conclusion for all groups was that the fee decreased profits for all fossil fuel options with coal being the most costly. Yet, the carbon fee is a complex and controversial issue. The original design did not successfully integrate the complexity of the concept.

Since originally introducing the project, the Design of Thermal Fluids Systems course instructor became aware of both the World Energy Exercise and efforts at the state level to introduce a carbon fee. Both of these items served to transform the standard design project into a very engaging learning experience.

The revised project, which includes World Energy, now utilizes three additional class periods which were previously compensatory time for the students to work on their designs. One of the class periods is a forum for a guest speaker (or speakers) to address the idea of a carbon fee. This forum makes the issue real. Speakers have included officials from both the state government and nonprofit organizations who are aware of benefits, challenges and limitations of a proposed carbon fee. The carbon fee is no longer a simple number provided in the design, but a controversial issue which not everyone agrees on. How, when and if a fee should be implemented is a topic to discuss and debate.

After gaining a better understanding of the fee from the guest speaker, the students are asked to consider the fee in a larger context. That is, should all states or even nations consider a carbon fee? Are there other options to reduce greenhouse gases in the atmosphere? Now the door is open to address this complex issue, however with a large class of over 100 students and very limited time, care must be taken to address the issue in an organized and engaging way. The World Energy Exercise is the method for further exploration; it helps students learn more about the interface of engineering, science, and policy in way that is engaging and motivating, while also being scientifically rigorous. It is conducted as an in-class exercise over two 75 minute class periods. The exercise replaced compensatory time formerly used to complete the actual steam power cycle design.

Introducing World Energy

Although the carbon fee guest speakers help to make the design problem realistic, this forum is not very interactive and it is generally focused at state-level initiatives. Anthropogenic climate change is a much larger issue and it is not a problem solved by merely adopting a carbon fee. To assist the students in understanding the magnitude and scope of the issue, the Kaya Identity Equation is developed. Although the equation is a readily know "I-PAT" equation, human impact (I) on the environment equals the product of Population, Affluence, and Technology (PAT), where the impact is carbon dioxide in the atmosphere, the equation is potentially a new, yet easy to interpret concept for the engineering students.[4] Asking where the anthropogenic carbon dioxide comes from in the form of a series of leading questions can generally form the Kaya Identity Equation as represented below.[5]

$$CO_2\ Emissions(tons) = Population * \frac{\$GDP}{Population} * \frac{Energy\ Unit}{\$GDP} * \frac{CO_2\ Em}{Energy\ Unit} \quad (1)$$

The equation shows that the total carbon dioxide emissions level can be expressed as the product of four inputs: human population, GDP per capita, energy intensity (energy use per unit of GDP), and carbon intensity (emissions per unit of energy consumed). Note that the students' power cycle design and fuel choice would impact the carbon intensity term. The equation is developed so that the students not only see how their designs impact global CO_2 emissions, but how very few known numbers can be used to calculate a seemingly complex value. The equation also illustrates how carbon dioxide emissions can be projected into the future based on projections of the values on the right hand side. As part of the World Energy Exercise, the students are then assigned roles that enable them to influence the values on the right hand side, to generate a carbon emissions pathway into the future and to discover the impact of the emissions on global average temperature.

The World Energy Exercise

The World Energy Exercise, created by Climate Interactive and the UMass Lowell Climate Change Initiative, is currently under development.[6] A pilot version used in the Design of Thermal Fluids Systems course is fully functional and is available for demonstration and exploration. It is important to note the World Energy Exercise along with the supporting simulation software (En-ROADS) is a sophisticated model, yet simple enough to be understood by undergraduate engineering students, policymakers, educators, civic leaders and interested persons in the general public. The simulation runs in a few seconds on a laptop computer; this allows for users of the software to receive almost immediate feedback. The simplicity and speed of the model are necessary elements in order for the general user to gain an overview of the relevant energy and climate dynamics. The model is calibrated to represent state-of-the-art climate models, however the geographic and temporal resolution of a state-of-the-art climate model is not captured.

Other aspects of the climate-energy system that are introduced prior to beginning the exercise include:

- Several anthropogenic greenhouse gases contribute to climate change, not only carbon dioxide. (The source and relative strength of all greenhouse gas emissions are presented.)
- The physical science basis of the greenhouse effect.
- Global warming is already causing many negative impacts, including sea level rise, and if emissions are not checked, may cause catastrophic outcomes.
- International climate goals, formalized by the Paris Agreement of 2015, call for "emission pathways consistent with holding the increase in the global average temperature to well below 2 °C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5 °C."[7]
- The goal of the World Energy Exercise is the same; to create an emissions pathway which results in a global mean surface temperature rise of less than 2 °C above preindustrial levels.

With the goal of establishing an emissions pathway to keep the global mean surface temperature to a less than 2 °C rise, the class assumes various roles in charting the future emissions pathway. The class is pre-assigned into one of six roles:

(1) Population and Consumption. This group can control policies that influence the growth of population and consumption linked to energy use (e.g., educating and empowering women, reproductive health, interest rates, etc.)
(2) Energy Efficiency. This team represents leaders from both the mobile and stationary energy intensive sectors of the economy. It makes decisions concerning the rate of improvement in energy efficiency over the coming decades.

(3) Carbon Pricing. The carbon pricing team represents the governments for the world's largest economies (and leading emitters). Although there is no current international body that could enforce an international price on carbon, implementation of carbon pricing policies are growing internationally. Many economists agree that carbon pricing is the most effective and economically efficient way to reduce carbon emissions.[8] This team sets a future carbon price for the global economy.
(4) Energy Supply. This group represents two major types of energy suppliers; two thirds of the group represents fossil fuel producers and the other third represents low carbon and renewable energy suppliers. They make decisions to tax, subsidize, or invest in breakthrough technology development for all sources of energy.
(5) Land and Agriculture. This group represents large agricultural companies and producers, landowners, and organizations representing smaller agricultural producers. It makes decisions regarding global forestry and agriculture. It represents the people and companies that feed the world.
(6) Climate Hawks. This group represents the leaders of the climate action movement and climate think tanks across the globe. They lobby all other groups for the strongest possible action to address climate change. This group makes no decisions and has no real power, but they potentially have a strong voice.

In many cases, there are tensions implicit in the roles that each group is playing. That is, if the group fully accepts the diversity in their various roles, the group members may have opposing views. Furthermore, the groups representing policymakers such as the carbon pricing group are encouraged to listen to their stakeholders: energy supply, energy efficiency, population, and land use. Thus, each group must attempt to come to a consensus internally on the correct policy or action to implement, and also address pressures from the other groups.

The roles are very diverse and students often personalize them; they may become the Secretary of State, the Pope, the CEO of Chevron, or Tyson Foods. All of the 'big players" with the influence to affect global climate change have gathered in one room and the competing agendas suddenly fill the room with debate. Each group is asked to come to a consensus concerning how their area of influence should behave in the coming decades. The groups provide a five-minute briefing to the class explaining who they represent, what policy levers they have control over, and what policy they chose to implement to assist in reaching the 2 ^{o}C goal. They then make the adjustment in the actual simulation software and the entire class can immediately see the impact; that is, all see the effect of a proposed policy on the emissions pathway. All groups except for the Climate Hawks adjust a lever, which impacts the carbon dioxide equivalent concentration in the atmosphere. The simulation software, En-ROADS, will display a variety of graphs giving students real time insight into the impact of their proposals. After the initial proposals are made and the class fails to meet the 2 ^{o}C goal (this is typically the case), groups are then asked to negotiate with the other groups. The groups try to get "everyone else" to do more, so that collectively the class can succeed in achieving the goal.

The En-ROADS Simulation

En-ROADS is the "Energy-Rapid Overview and Decision-Support" simulator. It is the online simulation tool that allows the students to get immediate feedback on the impact of their decisions. It is still under development by Climate Interactive and a host of collaborators.[9] The simulation is calibrated with extensive research on factors, which impact energy use such as price sensitivities, historic growth of energy sources, and energy efficiency potential. It includes sufficient complexity to illustrate dynamic interactions between the different levers at play through a user-friendly interface. While understanding the underlying equations and assumptions in En-ROADS would require substantial further effort, it has a user-friendly interface that makes it easy to manipulate levers and gain insights into the overall behavior of the climate and energy system.

Running the En-ROADS simulation in real time allows the students to witness how their proposed changes in taxes, subsidies, economic growth, energy efficiency, technological innovation, and carbon pricing, impact global carbon emissions and global average temperature. All of the graphs produced compare the results of the scenario created by the class to a reference, or "business as usual" scenario. The students are able to understand the basic science embedded in the simulation, but also realize that social and economic considerations drive the decisions and policies.

The output of the En-ROADS simulation includes a myriad of graphs that are easy to interpret. In Figure 1, the annual forecasted carbon emissions is plotted to the year 2100 and compared to both the reference scenario, as well as the pathway needed to achieve the 2 ^{o}C goal. Students are able to note that a horizontal or flat line from the current year will not be sufficient to reach the goal, and near-term and aggressive actions are needed to achieve the goal.

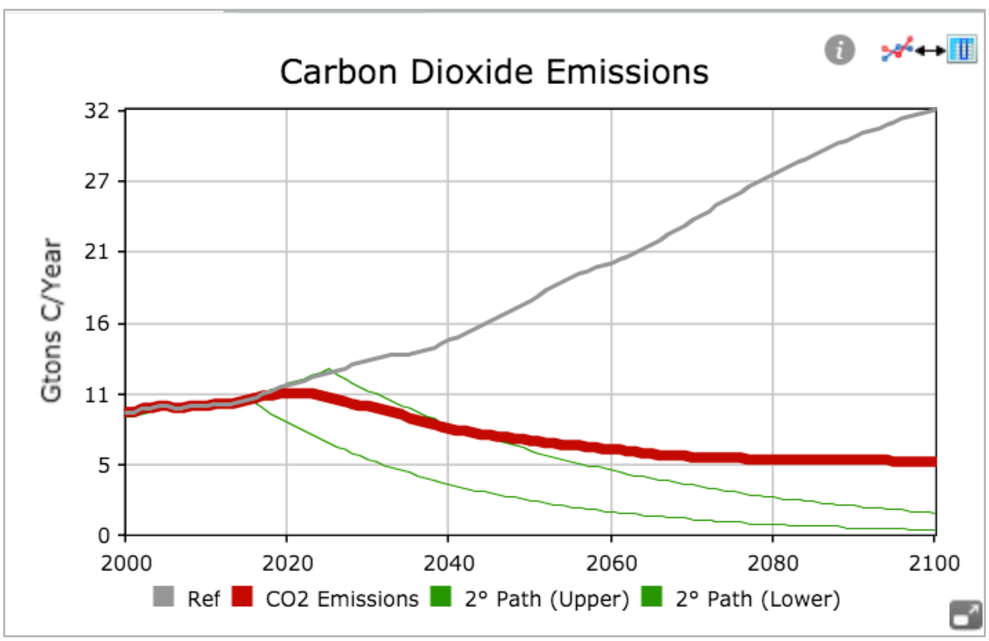

Figure 1. En-ROADS Sample Output, Expected Carbon Emissions Pathway. The grey line represents the 'business-as-usual' reference scenario; the thick red line represents the emissions pathway generated by En-ROADS analysis of the decisions students have made; and the green lines provide upper and lower bounds for a +2 ˚C outcome considering the simulation's climate sensitivity model.

Temperature change over time is another parameter that can be used to illustrate the impact of students' policy decisions (e.g., Figure 2). In fact, temperature outcome is generally more tangible to students than emissions, which are given in Gtons/year and may be difficult to relate to, as mechanical engineering students do not typically work with the concept of global emissions. Students quickly see whether their scenario meets the goal, and also notice in their mature adult years, approximately 2050, the world is forecasted to be an average of 2^o C warmer than pre-industrial levels, only approximately 1^oC warmer than current mean temperatures. Although this increase may seem insignificant, the consequences of the predicted temperature increase by 2100 are presented; the results are sobering. The impact of a small increase in temperature is a substantial learning point for the engineering students, one that was likely never formerly addressed in their engineering courses. As a class, the engineering students worked earnestly to create a pathway with significant reductions in greenhouse gas emissions. Unfortunately, the pathway still represents a significant increase in the likelihood and intensity of drought, wildfires, heat waves, water shortages as well as sea level rise. The numerous consequences of various scenarios are outlined in one of several supporting slides prepared by Climate Interactive and the UMass Lowell Climate Change Initiative. This idea of a small temperature change creating a significant impact on the weather and all life on the planet is a topic for further individual exploration; for many students their curiosity is sufficiently stimulated.

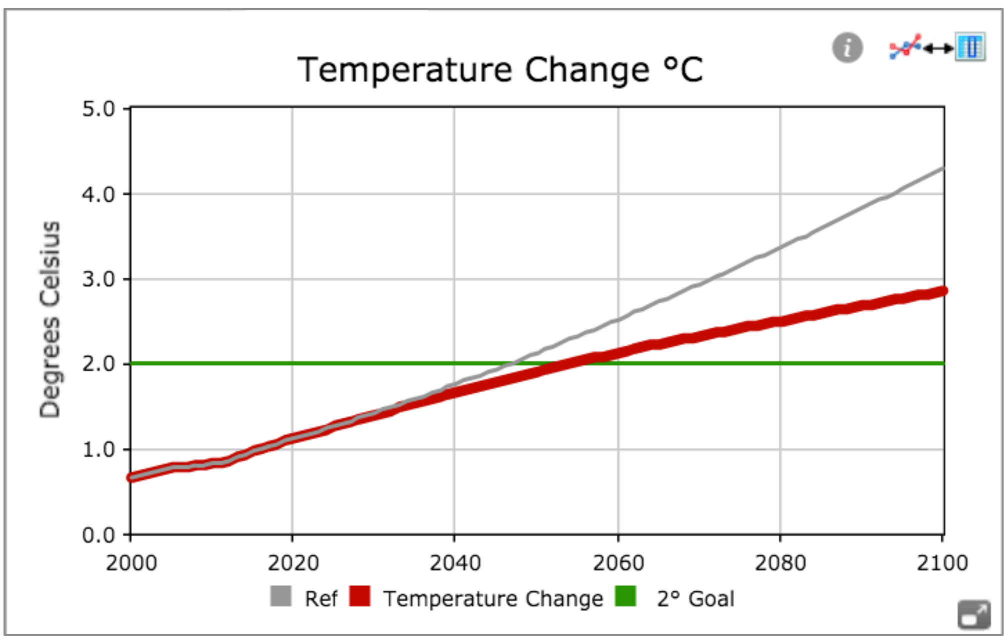

Figure 2. En-ROADS Sample Output, Expected Change in Global Mean Surface Temperature. Here, the green line represents the +2 ˚C goal, while the red line represents output from the current run and the grey line represents a 'business-as-usual' reference scenario.

All of the associated resources to run the World Energy exercise are conveniently provided by Climate Interactive and UMass Lowell Climate Change Initiative. They include access to the En-ROADS simulation, introduction slides to explain the exercise, instruction packets personalized for each of the six groups, information sheets providing data on greenhouse gas emissions, GDP and other concepts engineering students or the general public may be vaguely familiar with.

Although Figure 2 illustrates a clear success or failure with respect to achieving the goal of the World Energy exercise, the En-ROADS simulation is able to provide greater insight for curious students. For example, other accessible graphs include the Kaya Identity factors as shown in Figure 3. Engineering students may likely be unfamiliar with the current and projected world population and have little awareness of the relative GDPs and energy use of their own country compared to elsewhere in the world. Although the graphs in Figure 3 represent global averages, they can prompt much discussion about the regional variance in the data, for example the GDP per capita in the US, China and India is an interesting digression. The Kaya Identity plots also provide students with a positive feeling as they see the population and GDP per capita increase, while carbon emissions decrease.

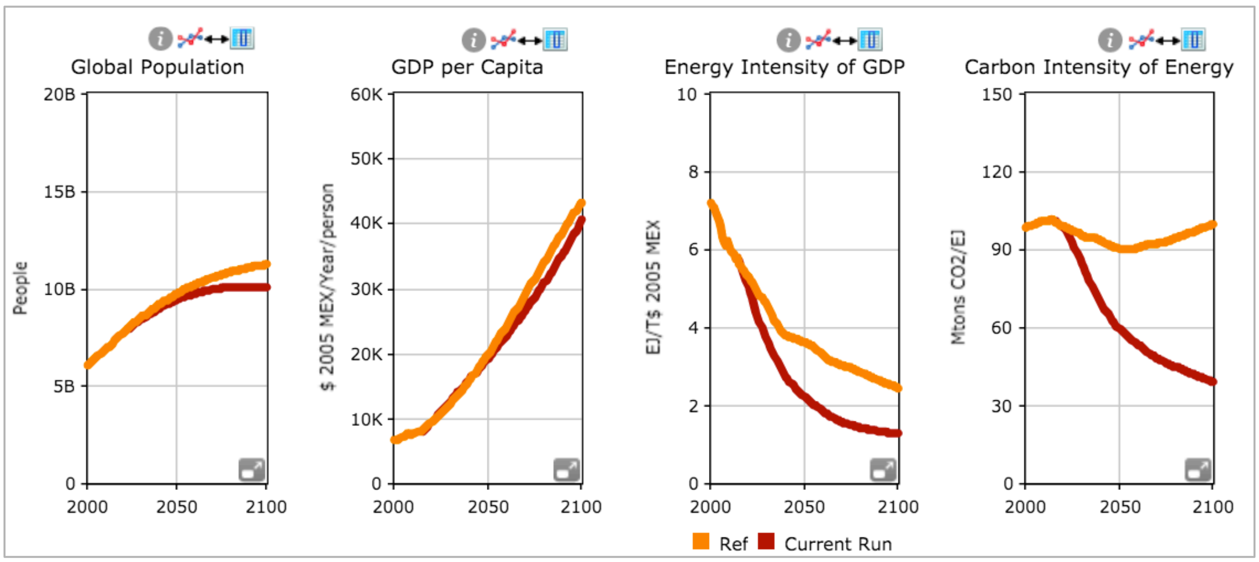

Figure 3. En-ROADS Sample Output, Kaya Identity Factors.

Use of the Simulation, En-ROADS in World Energy

The World Energy Exercise is the name of the overarching exercise that utilizes the En-ROADS simulation software. In Design of Thermo Fluid Systems, students were assigned groups with specific roles as part of the World Energy Exercise. Each group was responsible for adjusting certain levers in the En-ROADS software. For example, the Land and Agriculture group controls levers associated with land use and forestry, as well as emissions of methane, nitrous oxide and "f-gases" such as chlorofluorocarbons. Each group must develop a proposal to explain to the class how they intend to adjust the lever. The proposals are short five-minute informal presentations, usually without graphics or visual aids. This proposal contains specific values, which are input into the simulation software, En-ROADS. The result of the proposal is almost immediately visible. The combination of the inputs from all of the groups results in an emissions pathway such as the one illustrated in Figure 1.

In the first 75-minute class period, students discuss their assigned role within their group, come to a consensus on their proposal and present the proposal to the class. All proposals are input into En-ROADS and the resulting carbon emissions pathway is visible. Typically the class will not achieve the goal of creating an emissions pathway which results in a global mean surface temperature rise of less than 2 °C above preindustrial levels. Thus the process is repeated during the subsequent class period with an increased emphasis on getting the other groups to do better with their proposals. Students realize that even in a fictitious academic setting, the competing agendas of the various stakeholders as well as real world constraints, make significant progress challenging.

Results and Discussion

The goal of incorporating World Energy into a senior level engineering design class is to help students appreciate the real-world societal relevance as an integral part of design, rather than to simply acknowledge nontechnical issues at a superficial level and focus on a technical design. Student reflections and survey results reveal that the exercise not only achieved the goal, but may have been a transformative learning experience for some. Each student provided an individual reflection as part of the group's design submission. Provided below are a few excerpts from the individual reflections:

> *The World Energy exercise increased my sense of personal responsibility to the environment.*
>
> *This really discouraged me at first, but after some contemplation, it has really seemed to rekindle my desire to want to help in the fight against climate change.*
>
> *Participation in the World Energy Exercise provided an improved understanding of how the issue of climate change is not simply solved by a handful or individuals practicing "green ' lifestyles. The answer isn't telling everyone in America that they need to drive a Prius. It shows that the answer requires cooperation and coordination on a massive and intimidating scale.*
>
> *I was happy to have a class project which focused on climate change and the political and social challenges that accompany it. It is critical to educate people in this fashion in order to raise a generation that will support climate change action.*
>
> *Climate Change was shown to be an issue that most of our class has yet to research or discuss. The discussion seemed to create motivation in some students but not all are convinced.*

As shown in Figure 4 below, approximately half the student responded that the exercise created a renewed sense of responsibility and urgency. When asked, "Has there been a change in your sense of urgency concerning the need for taking action to combat climate change?" 45% of the class responded affirmatively while 37% already thought the problem was urgent. In 2015 a combined 82% of graduating engineering students who consider the problem urgent is a substantial majority, and with their technical expertise about to go to work, the timing of the inspirational exercise is noteworthy. In 2016 the percent of students who responded that climate change is more urgent or has always been urgent increased to 88%.

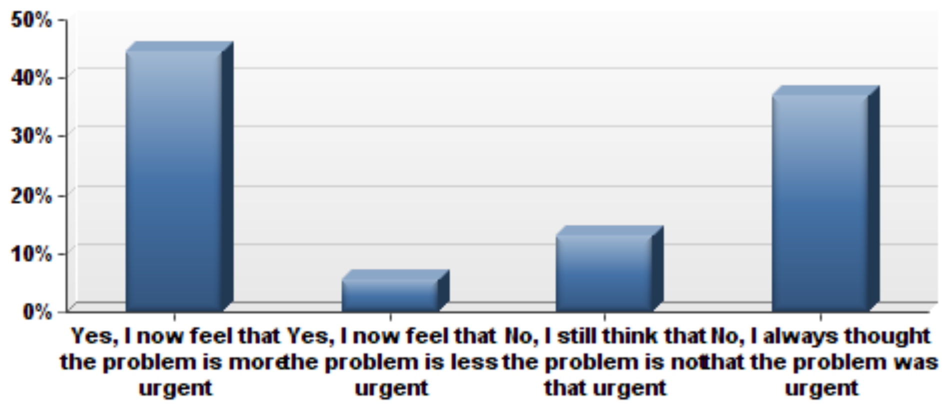

Figure 4. Survey Response: Has there been a change in your sense of urgency concerning the need for taking action to combat climate change? (n=93)

When asked how the World Energy exercise affected the student's desire to learn more, 66% percent of the class wanted to learn more about the potential solutions for mitigating the effects of climate change, and approximately half wanted to learn more about the science, economics and policy related aspects.

Question	Want to learn more	No change	Less interested
The science of climate change	49%	49%	2%
Potential solutions for mitigating the effects of climate change	66%	32%	2%
Economics as it relates to climate change	46%	45%	9%
Energy Policies	42%	52%	5%

Figure 5. Survey Response: How has participation in the game affected your desire to learn more about the following? (n =93)

Although the exercise was only moderately engaging for most students during the initial trial, the engagement was significant considering the number of students involved in the role-play exercise. In the subsequent rendition of World Energy (2016) minor modifications were to make the exercise more engaging. Specifically the En-ROADS software was made available to each group rather than controlled by the exercise facilitator/instructor. The number of students reporting that the exercise was very to moderately engaging increased from 76% to 83%. It is important to note that the engagement illustrated in the figure below was predominately supplied by student peers. That is the exercise consists of students explaining, defending and questioning policies related to global climate change rather than the instructor leading the engagement. The exercise as it was first conducted consisted of twelve groups of approximately ten students. Conducting a role-play exercise with 120 students in a large auditorium is not the optimal setting, but it still created a significant level of engagement.

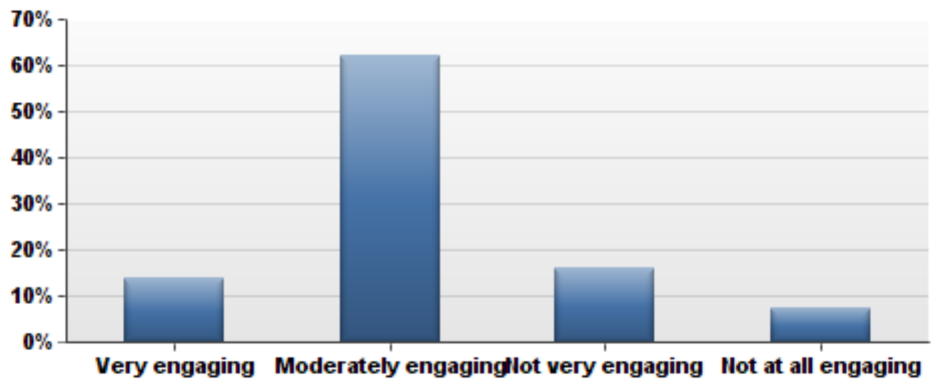

Figure 6. Survey Response: How engaging did you find the experience of participating in the game? (n = 93)

Gaining a better understanding of the impact of engineering solutions in a global, economic, environmental, and societal context, recognizing the need to work with others across national boundaries and societal sectors, and instilling a desire to learn more about the complex dynamics of climate change are some of the significant outcomes of this short exercise. The fact that the computer simulation supporting the World Energy Exercise is also used to support high-level decision-making about climate change and energy policy, also drives home its relevance to an internationally important societal issue. Although the exercise requires significant planning and approximately two and a half hours of class time, its impact is significant as evidenced by the data provided above.

Eighty percent of the class reported satisfaction with spending in-class time on the nontraditional role-play exercise, while the other twenty percent wanted to spend less time or omit the exercise. Regardless of whether or not the students found the exercise engaging, or departed wanting to learn more, virtually every student reported a significant learning experience. When asked, "What is the most significant thing you learned by participating in World Energy?" many students provided a response which illustrates both the breadth and the depth of the exercise. A selection of student responses are provided below:

> *The most significant thing I learned during the exercise is the amount of variables involved in attempting to solve the global climate issue. There is no one method to fix every problem, and there needs to be a contribution from everybody to address a vast majority of these problems.*

That we need to make a change while we still can to prevent climate change from getting any worse. It's going to require the whole world to get together and participate to make this happen. Greed has to be left out of the equation or it will never happen.

The need for everyone to work together, to be able to accomplish anything. That means world powers, 3rd world developing nations, politicians and companies need to work in unison towards lowering the carbon output.

That the human condition is to help ourselves before we help others. A person may want to effect change and be willing to sacrifice something for it, but the people with the power do not want to sacrifice what they have to better the world.

It was one of the most interesting not talked about issues I ever learned about and I learned about how important reducing carbon emission is for our environment.

The most significant thing that I learned was the amount of contributions that we as a whole have to make to correct this problem. There is no one easy answer and the solution will be painful. But the reward will be worth it.

After World Energy

After completing the role-play /simulation, the negotiators resume their student roles to complete their technical designs, but they now possess a greater sense of the significance of designing a power plant under carbon pricing policies. The World Energy Exercise is clearly academic, that is for the purpose of establishing connections in the extent of the various levers impact on global climate change. The exercise allows the students to relate their technical work to real-world problems and policies, which can then be incorporated into their team's design and in life beyond their undergraduate formal education. As the societal discourse about the issue of climate change continues, many students who have experienced World Energy and considered the implications of policies such as carbon pricing on engineering design will be better prepared to enter that discourse with an informed perspective. In reality, there will never be simple levers to adjust on a laptop computer to change global policy and greenhouse gas emissions, yet there are real people across society working tirelessly to do their part.

Conclusion

The idea of running a climate change simulation for a group of engineering students with no professed interest in the subject can be unnerving, however the resources provided by Climate Interactive and the UMass Lowell Climate Change Initiative make the project manageable, even for educators with no formal background in climate science. As many of the students so articulately stated, addressing the problem of climate change will take everyone, not the actions of a few, to be successful. "Everyone" includes engineering educators. Engineering education can play a greater role in the climate change mitigation effort by formally incorporating the complex dynamics of anthropogenic climate change into the engineering curriculum. The World Energy Exercise is a very effective, relatively quick, and enjoyable tool to explore such a complex topic. More detailed information and facilitator resources can be accessed at https://www.climateinteractive.org/programs/world-energy/.

Incorporating the exercise into an engineering design problem rather than as a stand along learning experience, seemed to ignite passion in the students in both their design problems and desire to want to learn and do more. Although the World Energy Exercise did not change the students' technical power cycle designs, it provided students with an interactive and engaging learning experience, which both broadened and deepened their understanding of the problem. Undoubtedly the students completed the design realizing that the technical analysis is not the only "problem" which needs to be solved. Furthermore, student reflections reveal that the exercise deepened their understanding of the nontechnical issues not only in the power plant design, but in life in general.

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