How might the coming climate crises change the way we teach economics? Using the Green Business Lab © to help students connect the dots

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Abstract

Climate change is a complex and ill-structured interdisciplinary grand challenge problem that lacks a simple solution. Teaching about such problems is fraught, because there is no "answer key," collaboration across disciplinary boundaries is difficult, and differing assumptions and methods can inhibit success and reduce likelihood that objectives will be shared and interpretation of results can be agreed. Yet, students should develop dispositions and attitudes that enable working on grand challenge problems like climate change. An important question is "how can we teach and learn when the instructor doesn't know the answer?" We argue, based on lived experience in the classroom, that team-based learning pedagogies using realistic in-class simulations are an effective way to teach undergraduate students interdisciplinary problem-solving skills applicable to grand challenge problems, even at the introductory level. We provide an example of implementing those pedagogies with the Green Business Lab, an extended and realistic business simulation wherein students play roles as managers who design, market, and sell an electric-powered "SphereMover" in a competitive market. Benefits of the Green Business Lab include co-construction of meaning among students, high levels of student engagement, and enhanced instructor satisfaction. Students learn boundary-crossing skills and gain confidence to integrate knowledge from different disciplines. Practical tips and implementation suggestions are discussed.

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Introduction

In 2010, Robert Shiller asked the question, "*How should the financial crisis change the way we teach economics?*" In his answer, Shiller suggests that economics education needs to incorporate interdisciplinary perspectives, including "those promoted by the other social sciences: psychology, sociology, political science, and anthropology" (Shiller, 2010, p. 407). Today, a similar question could be posed: "*How might the coming climate crises change the way we teach economics?*" As a first step, Liu, Bauman, and Chiang (2019), suggest that we should "be giving more prominence to climate change in introductory texts." And as a second step the authors referred back to Shiller's advice and called for deeper interdisciplinary ties between economics and other perspectives, saying "[c]limate change is an even more interdisciplinary subject than financial crises, so the same reasoning applies." Thus, a continued and renewed push exists for economic curricula to incorporate other disciplinary perspectives and give prominence to climate change issues.

The second author of the above article is well known stand-up economist Yorum Bauman, carbon tax activist, and author of *The Cartoon Introductions to (Micro and Macro) Economics* and *The Cartoon Guide to Climate Change*. In working to bring climate change (and other issues) to prominence in economics education, Bauman has pushed pedagogical boundaries. A few others within the economics discipline have thought creatively about how to expand climate change curricula as well. Fortmann, et al. (2020), for example, share their computational guided inquiry modules, which use real-world data and economic concepts to value climate change impact on the Arctic. However, in general, climate change education within economics is confined to discussions of externalities and tragedy of the commons (Liu, Bauman, and Chiang, 2019). While externalities and common goods are important for understanding climate change policy and mitigation, economics has a great deal more to contribute to addressing climate change than these two topics.

The desire to provide an introduction to economics that gives prominence to climate change was the motivation behind the creation of an introductory-level economics class entitled, *The Economics of Energy and Sustainability*. While the class is not a general introduction to economics *per se*, it is designed to provide an introduction to economics for non-majors. Indeed, it meets the university's core requirements for an introduction to social science. It uses an explicit interdisciplinary approach. It was designed by and is currently co-instructed by an economist and an engineer, but the course does not require students to have prior knowledge of economics (or any other discipline).

A challenge of course design was to provide enough economics content so that students from STEM, social sciences, business, and humanities can understand the theories of consumer and firm behavior, markets, the public sphere, growth models, and macroeconomic measurement. And, provide enough interdisciplinary material to accompany the economic content to describe the complex relationships between the economy and climate change. With the breadth of material in the course, a "through line" was needed. We chose the *Green Business Lab* to assist students to make connections between economics, energy, and climate science.

The *Green Business Lab* (GBL) is an extended and realistic business simulation. In GBL, students take on roles as business managers who design, market, and sell an electric-powered "SphereMover." Teams of students form companies who compete against each other (and additional simulated companies) over three business cycles in a simulated competitive market for SphereMovers. During the business cycles, the students redesign their prototype based on the previous cycle market results. The market results include sales metrics, as expected, but also energy consumption and pollution impact data. The teams are evaluated on their profits as well as the energy and pollution footprint of their product. The simulation helps students draw a direct line from the economic decisions made by consumers and firms to the impact of those decisions on energy, emissions, and ultimately the climate.

The purpose of this paper is to describe how the *Green Business Lab* (GBL) can be used to teach introductory economics, particularly, but not necessarily in an interdisciplinary setting. We open with a brief overview of the literature related to three key facets of GBL: (a) team-based learning, (b) extended simulation, and (c) interdisciplinarity. We then describe how the simulation works from both the student and instructor perspectives, what learning objectives it achieved, and how it was assessed. Appendices contain supplementary teaching notes and materials.

Background

In this section, we discuss the literature in three areas germane to the simulation discussed in this paper: (a) team-based learning, (b) classroom simulations, and (c) interdisciplinary teaching and learning. Due to space limitations, we do not provide a comprehensive review of previous studies in any of the categories above. (For excellent reviews of these topics, interested readers may refer to papers cited in this article, many of which provide comprehensive literature reviews.) Our intent is rather to define terms and provide examples to illustrate a consensus in the literature that team-based learning via extended in-class simulations is a particularly effective pedagogy for teaching economics in an interdisciplinary setting.

Team-based Learning (TBL)

The literature shows that Cooperative Learning (CL) and Team-based Learning (TBL) generate improved learning outcomes in students and enhanced engagement by instructors. Swanson et al. (2019) performed a meta review of 17 studies and found that TBL "improves students' end of course grades, test performance, and classroom engagement" (p. 39). They focused their review on content knowledge acquisition and found that TBL has a moderate positive effect that improves with smaller group size (fewer than 5). "Co-construction of meaning" via in-group conversation is a means by which content knowledge is cemented in the context of TBL. (p. 47)

Cañabate et al. (2020) surveyed 162 students across 7 university disciplines regarding CL. They found positive student perceptions of their own motivation and learning outcomes. Students report that they learned more in the time spent in CL than in the time spent working individually. They found that student motivation in CL activities correlates with well-organized activities where the instructor was heavily involved. "[A]ctive intervention and constant feedback from the lecturer/professor is considered necessary … to carry out an autonomous, shared, and critical learning process" (p. 15). They noted that good interpersonal communication in student teams correlates with positive CL outcomes.

Imazeki (2015) shows that TBL is beneficial for learning outcomes in economics courses specifically. (The focus of the Imazeki paper is an application of TBL in a data analysis course.) Imazeki finds that TBL is a way to engage students in material that spans an entire course. In a TBL environment, students are able to work effectively on "more complex problems than would otherwise be possible" (p. 399). She notes that implementing TBL strategies in a classroom requires the instructor to invest significant start-up time.

Thus, we see that CL and TBL improve student outcomes so long as student group size is small (less than 5), group dynamics are positive, activities are well-organized and exhibit real-world complexities, and instructors provide continuous feedback. In CL and TBL classrooms, typical "chalk and talk" and "stand and deliver" teaching is eschewed. But more student learning is achieved. Or, as the saying goes, "less teaching, more learning." (Luckie, et al., 2012)

Simulations

When done well, team-based learning improves student outcomes. But setting the stage for TBL to succeed can require significant up-front investment by the instructor. So, why introduce the additional complexity of an extended simulation (a simulation that occurs over several class periods) on top of team-based learning? First, using well-developed pre-existing simulations can reduce setup time for TBL. Second, extended simulations can complement and enhance TBL. As stated above, when TBL engages a significant, realistic problem with a common objective, as can be the case in an extended simulation, the benefits of TBL are magnified.

Extended simulations allow students to dive deep into a realistic problem, thus motivating them to learn and apply knowledge content. Extended simulations give teams several class periods to work through the problems, questions, and challenges that arise in a realistic situation. Realistic problems have unclear goals, multiple solutions, multiple solution paths, and uncertain evaluation criteria. In short, they are ill-structured problems. Extended simulations give students time to wrestle with complex, ill-structured problems and develop knowledge and skills required for engaging them. (Imazeki et al., 2015, p. 403)

In the classroom setting, the effectiveness of a simulation depends on re-creating the minimum necessary conditions of a realistic problem combined with appropriate levels of scaffolding provided by the instructor. A benefit of extended simulations is that students immerse themselves in real-life challenges and experience the entire life-cycle of economic analysis while having systematic guidance to keep them afloat. In Hertel and Millis' (2002) excellent introduction to using simulations in higher education, they describe the "magic" that can happen when students are given additional time to process the disciplinary material in a realistic context, and observe others doing so as well. (93) Time is the key element. Particularly in a course where students are asked to understand complex relationships among variables, a simulation that spans several class periods provides time for students to encounter multiple facets of those relationships.

Chernikova, et al.'s (2020) meta-analysis of the effects of simulations in higher education classrooms also provides strong evidence that duration is one of the key components of effectiveness. They analyzed 145 independent studies of problem-based simulations and estimated 409 effect sizes over various facets of simulation design. Specifically, they examined simulation type, duration, use of technology, and authenticity (realism). One of the key findings of the meta-analysis is that effect size is highly correlated with the duration of a simulation. The longer the simulation, the larger the impact on students' improvement in critical thinking and problem-solving skills. Their estimated effect size of an extended simulation (more than one month) was double that of a simulation that took place in one class period. Johansen et al.'s (2009) study of interdisciplinary team-based business projects found that student satisfaction and engagement with a team-based project was significantly positively related to the duration of the project.

Forms of instructional support also contribute to the success of simulations. Chernikova et al. examined effect sizes for interactions between forms of instructional support and students' level of prior knowledge.The effect size for using prompts (questions that help clarify suggested actions) when students have low levels of prior knowledge was found to be statistically significantly larger than when simulations had no prompts. Overall, compared to other pedagogical approaches, Chernikova found that extended simulations improved learning outcomes for engaging ill-structured problems even in undergraduate classes where students had little prior knowledge. The most successful simulations incorporated instructor support in the form of examples, prompts, and opportunities for reflection. Thus, appropriately scaffolded extended simulations provide a beneficial classroom structure for "less teaching, more learning."

Interdisciplinarity

Grand challenge problems (such as climate change, pandemics, human development) are complex and multi-faceted. They lack simple solutions. They are ill-structured and interdisciplinary. Each discipline can make partial contributions to solutions, but an "all hands on deck" approach is needed. However, collaboration across disciplinary boundaries is often fraught. Differing assumptions and methods can inhibit success and reduce likelihood that objectives will be shared and interpretation of results can be agreed upon.

Interdisciplinary problem-solving around grand challenge problems is even more fraught for students in foundational courses who are learning fundamental concepts of their disciplines. But providing space for students to experience collaborative, interdisciplinary problem-solving is essential to equip them to engage complex problem solving in their futures (Zaman, 2010). In addition to disciplinary content, students need to learn "[b]oundary-crossing skills, … the ability to change perspectives, to synthesize knowledge of different disciplines, and to cope with complexity" (Spelt, et al. 2009).

Spelt, et al. identify several key attributes related to learners, instructors and curriculum that are essential to interdisciplinary learning outcomes in higher education. One of the most important attributes of the class curriculum is that it provides an "overarching framework" or "roadmap" that connects ideas for students. When students engage complex questions from within an ongoing, consistent framework, they learn to apply disciplinary knowledge and also how to connect to other disciplines and ask questions to gain additional perspectives.

Our approach to teaching introductory economics with climate change in the foreground brings the three topics above together. We use team-based learning (groups of 4-5) in a simulated environment (Green Business Lab) to enable interdisciplinary learning (economics, energy, and climate science) around a grand challenge topic (climate change). The next section discusses details of our approach.

Methods

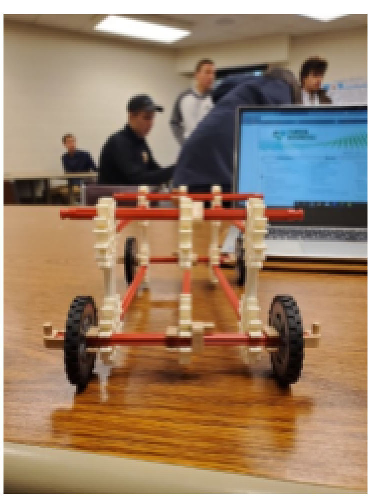
Why use the *Green Business Lab* to teach economics?

Bringing climate change more fully into economic education is not as easy as it sounds. Economic analysis typically involves closed-form solutions, especially at the introductory level. Yet problems related to climate crises are ill-structured, often having multiple solutions, multiple solution paths, or even no solution. How does one teach a topic when even the instructor doesn't know the answer? The three pedagogical approaches discussed above (team-based learning, extended simulations, and interdisciplinary curricula) have all been shown to help students achieve learning objectives related to gaining complex skills needed to engage ill-structured problems. When students inhabit roles in an extended, realistic simulation, they begin to viscerally understand what is at stake in climate change and how economics contributes to understanding the issues. They can see how to make progress on problems that seem intractable. They learn how to learn from failure and how to consider other perspectives.

Student Experience

The *Green Business Lab* is an example of an extended, team-based, interdisciplinary simulation. It is richly detailed and realistic, with students playing a manufacturing or marketing role in a firm. Student teams design, build, market, and compete in the market for a specific type of electric vehicle (a "SphereMover"). They are told that the executive team of the firm explicitly values the triple bottom line. Immediately, a complex challenge arises; students must perform multi-objective optimization for the firm. In addition to chasing profits, they must minimize environmental impact and enhance social outcomes. Thus, they must stretch across boundaries to understand how decisions made by profit-maximizing firms impact the environment and society. In addition, students experience the

Figure 1.



Hands-on Prototype Design

impacts of climate change on their decisions. One scenario has sea rise interfere with their supply chain. Via the GBL simulation, economic systems are presented as embedded within environmental systems, not separate from them. Students experience the theories of the firm and consumer behavior within the context of a grand challenge problem (climate change).

One of the most engaging and realistic aspects of the lab is that students design, build, and test the performance of a physical prototype using K'NEX components. (See Figure 1.) The lab is centered on the economic and environmental impact of the product design. Each of the K'NEX components (short red rods, long blue rods, white connectors, small wheels, etc.) has simulated economic, energy, pollution, and social impacts. The choice of a red rod rather than a blue rod in the design, for example, is associated with different direct costs, energy consumption, and pollution effects at each stage in the life cycle. In addition, students may decide to manufacture components in factories located in either the Industrialized Nations or Developing Nations. Manufacturing operations in the Developing Nations cost less, but produce greater environmental impact, pay lower wages, and have fewer regulations regarding worker safety. Students, however, can use investment opportunities within the simulation to improve worker conditions.

Every decision in GBL requires students to evaluate opportunity costs and make trade-offs. For example, blue rods are cheaper and have a lower environmental impact than red rods, allowing for a lower price, higher profits, and lower environmental impact. But consumers greatly prefer red rods over blue ones, analogous to customers preferring leather material over material made from recycled plastic, for example. The decision over which rod to use in the design leads to a complex optimization problem that must take into account multiple perspectives. For example, does the firm go with red rods to please the consumer, and hopefully find ways to reduce costs and environmental impact elsewhere? Or, does the company go with less expensive and lower environmental impact blue rods, and invest in a marketing campaign to try to persuade consumers to appreciate the benefits of material derived from recycled plastic? The simulation allows students to experiment and contrast the outcomes of both decisions.

The team-based aspects of the simulation are built into the design. Different roles (marketing, manufacturing, for example) have access to different information based on the responsibilities for their role. The manufacturing team designs and tests the SphereMover prototype. The marketing team estimates consumer demand based on expected competitors' prices and market appeal of the prototype. The prototype design and production quantity must be informed by the marketing team results. And the marketing results are based on the cost, energy efficiency, and pollution impact of the manufacturing prototype. The interdependency of the decisions within and between the marketing and manufacturing teams provides opportunities for conducting economic analysis guided by multiple perspectives. The immediate feedback that students receive from the market results at the end of each cycle gives students data for group discourse to help cement content knowledge (Swanson, 2019, p. 47).

The interdisciplinary aspect of the simulation comes from the constraints placed on students' decisions related to running their company. They receive input from stakeholders within the company as well as from outside the company. From the student perspective, the online component of the simulation appears as a self-contained company. The teams receive direct email communications from the company CEO and other internal and external stakeholders. These direct communications add realistic context to their economic decisions. For example, the CEO emphasizes that the team must maximize profits while generating the lowest energy and pollution footprint. Students receive email reflections on the cycle results from the perspective of internal stakeholders, such as the VP of human resources, and they are challenged to improve on areas that are not satisfactory. External stakeholders, such as political leaders in the communities surrounding the company's manufacturing plants, also email the students with information and requests. Thus, the students receive live dynamic feedback from within the world of the simulation, as well as feedback from the instructor.

Over the three semesters that we used GBL, students appeared to thoroughly engage the activities and meet the intended learning objectives. In anonymous course evaluation responses to the optional open-ended question "What aspects of this course most helped your learning?" twelve of the thirty-eight students enrolled in the class over the three semesters highlighted GBL, usually noting that it was practical and showed how all of the pieces of the course fit together. One student commented that "[t]he Green Business Lab helped me visualize all the different parts that we learned over the semester in a "real" world scenario. It showed me how all the different aspects of the class came together and helped me analyze the different questions this class brought about as well as bring up more questions that I want to look into more." One of the students suggested having a warm-up exercise. We implemented this suggestion the next semester, as discussed in the next section.

<u>*Instructor Resources*</u>

With the many layers of realism and complexity, the GBL simulation is a wide-open sandbox for students to experiment with economic, business, and environmental concepts. It is accompanied by in-depth, robust scaffolding for students and resources for instructors. The activities and format of GBL follow best practices in the literature. Student work is team-based and takes place in the classroom, making it easy for instructors to engage students and answer questions. Scaffolding for student learning is provided online via working briefs and creative tutorial videos. All students have access to the same background information and are debriefed together, which maximizes the peer-learning opportunities (Wedig, 2010, p. 550). Because students are arranged into teams that compete against each other in repeated market cycles, results are highly visible, motivating them to participate and learn from their decisions. (Wedig, 2010, p. 547)

Opportunities for learning and reflection come at natural break points in the simulation. The simulation entails three "business cycles." Just before the close of each business cycle, companies finalize their manufacturing and marketing decisions. Once the cycle is closed, the companies "compete" against each other in the simulated market. The market results are available immediately. Each team sees profits, units sold, market share, and environmental footprint for all companies. Guided class-wide discussions to analyze the overall market results are opportunities for students to make the meta-connections between economics and climate impacts.

The product "life cycle" framework of GBL is one of the most transformative learning aspects for students. Most students are accustomed to thinking of the environmental impact of using or disposing of a product. GBL helps students develop a more comprehensive awareness of the impact that occurs at all five product life cycle stages: raw material extraction, manufacturing, distribution, customer use, and end-of-life. In addition to decisions related to product design, students have the ability to make investment decisions that can impact costs and environmental impacts for all stages of the product life cycle. All of the investment decisions provided in the lab are based on real-world scenarios and students are given links to suggested readings for more information.

As with the manufacturing design decisions, each life cycle investment decision involves trade-offs. Some of the trade-offs are easily quantifiable. The lab tracks pollution emitted and energy used for each of the five life cycle stages of the SphereMover. The impact of investment decisions on costs, pollution and energy are based on realistic calculations. Pollution emissions from energy use are based on assumptions about the percentage of renewables used in the electric grid in industrialized nations or developing nations. Other costs and benefits of a life cycle investment decision are more subjective, such as valuing the effect on employment if the company decides to invest in pollution reduction technology at a manufacturing plant located across the globe in a developing nation. These decision making challenges give students opportunities to see the importance of engaging multiple perspectives.

While helpful for allowing students to experience the complexities of an integrated problem, the complexity of the simulation can also be overwhelming and frustrating without additional instructor guidance. GBL comes with robust scaffolding for students and instructors. GBL has students take a formative assessment quiz at the end of the practice cycle that covers the intent and mechanics of the simulation. Supplemental teaching notes for implementing GBL in the specific context of an undergraduate, introductory economics course are included in Appendix A.

We also supplemented the excellent tutorials and background materials that come with the lab, with a highly stylized (read - closed-form problem) warm-up assignment that gave students experience with the four key activities in the lab: (1) design and performance test a prototype, (2) calculate the direct costs and energy impacts at each stage of the product life cycle, (3) estimate market demand, and (4) estimate the market evaluation score (used by the simulation in determining market share). See Appendix B for the warm-up assignment and solution. In the future, GBL plans to add the ability for professors to share supplemental teaching notes and tips such as these through the App itself.

Class-wide discussion of the results from the warm-up exercise was used to connect the lab activities to the applications of the theory of consumer demand and profit-maximization, as well as draw the connections from economics to energy, environmental, and social perspectives.

<u>Learning Objectives and Assessment</u>

Our learning objectives for GBL are related to understanding complex, ill-structured problems:

1. Understand how consumer preferences constrain and encourage low environmental impact and socially responsible managerial decisions.
2. Understand the incentives profit-maximizing firms have to reduce environmental impact and enhance social outcomes along all five stages of the product life cycle.

Student assessment is a challenging part of teaching and learning complex, ill-structured problems. Indeed, how can the instructor know if students have done well if there is no single correct answer? One strategy GBL uses is to have students identify the business challenges and their performance objectives for each business cycle. At the close of each business cycle, but before the market results are shared, the teams prepare debrief reports that discuss the trade-offs they made and how they prioritized and justified their choices. Then, upon receiving the market results, students discuss in their groups how well their decisions addressed various business challenges and met performance objectives.

GBL gives instructors the ability to score open-ended questions on debrief reports for grading purposes and provide students written feedback within the Lab. The question prompts for the debrief reports can be customized. They can include reflective, applicative, summative, or integrative prompts to encourage self-reflection and extend student thinking beyond the boundaries of the immediate classroom experience. Table 1 contains a list of some of the debrief report prompts we used. These are designed to guide students through the process of thinking about the relationship between economic decisions and climate change. The debrief questions range from *reflective* ("Of the various decisions that the Executive Team made regarding energy efficiency or renewables, which was your favorite, and why?") to *applicative* ("What three valuable experiences … will you take with you and apply in the future?"). Student responses were evaluated on completeness and relevance to the question.

Table 1: Debrief Report Question Prompts

1. **Of the various decisions that your team made regarding energy efficiency or renewables, which was your favorite, and why? Was it because of:**
    - **a particular life cycle stage your team wanted to focus on?**
    - **a particular problem or issue your team particularly valued?**
    - **the values communicated to you by the CEO or other stakeholders?**

2. **Some of the life cycle impacts are not connected to company financials, but are externalities born by society (for example, pollution impact from raw materials or pollution impact during customer use). Were participants aware of this? What do they think about it?**

3. **After seeing other companies' presentations about how they prioritized projects, would they change their approach if they were going to do this again?**

4. **What three valuable experiences have you had from working with a life cycle approach and how can they be applied to your work or life?**

The summative assessment for the lab consists of a final presentation. The template for the team-based final presentation includes summation, reflection, integration, and application questions. (See Appendix C.) Teams are asked to "present (*summation*) and reflect on the key lessons learned from the Green Business Lab (*reflection*) related to how firms might contribute to a future reduction in energy consumption and GHG emissions (*application*)." Students are asked to integrate peer feedback with "**two discussion prompts** to invite responses to a question at the beginning of the presentation (*integration*) and reflect on something from the presentation at the end (*reflection*)."

Presentations are limited to 10–12 minutes and feedback is collected from peers and instructors. The assessment is conducted at the group level, but student scores can be adjusted by results of confidential peer evaluations and instructor knowledge of individual contributions. Students are rewarded for taking risks in the presentation, for example: trying something creative, working with someone they didn't know, bringing in material from other sources, bringing in their own reflections, background, experiences, etc.

Thus, assessment when there is no "right answer," can entail evaluating students' ability to describe what happened using categories from knowledge content, apply lessons learned, summarize their learning, and integrate their learning with peers. In short, students narrate their experiences and think about how their embodied learning will apply in the future.

Summary

Economics education needs to deepen its interdisciplinary ties so that the next generation of students across all disciplines will be equipped and motivated to bring economic thinking to the table when addressing the coming climate crises.

Given the importance of climate change, it is essential that climate issues be integrated into introductory economics education. But climate change is an interdisciplinary grand challenge. Like all grand challenges, climate change is an ill-structured problem with unclear goals, multiple solutions, multiple solution paths, and uncertain evaluation criteria. So how do we teach and learn when society and the instructors don't know the answer?

We think that team-based learning pedagogies using realistic in-class simulations are an effective way to teach undergraduate students interdisciplinary problem-solving skills, even at the introductory level. One example of that strategy is the Green Business Lab simulation. Many of the benefits of the Green Business Lab emerge from its structure: small groups of students participate in a simulation of extended duration involving in a team-based environment with pre-established roles for participants. Multiple reflection and feedback points are provided in a repeating, cycle-based framework. The structure of the Green Business Lab is beneficial for achieving complex learning outcomes, including opportunities for co-construction of meaning, high levels of student engagement, and enhanced instructor satisfaction.

How do you teach and learn when the professor doesn't know the answer? Do less teaching, and more learning with interdisciplinary simulations focused on grand challenge problems.

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Appendix A - Teaching Notes

The work of students and instructors are guided by the dashboards within the lab.

One way we reduced the cognitive load for our students was to reduce the size and complexity of the teams. Instead of groups of 6-7 students, with each student taking on a unique role on an "executive team," we put students in smaller groups of 4 or 5 students and boiled the separate roles down to just two. Thus, each student in the group was assigned to one of two teams: the Manufacturing team and the Marketing team.

We also restrict some of the decisions that students can make within the lab to make the market results more comparable across teams so that the outcomes from different decisions are more easily identified. Normally, teams choose where to assemble their product (developing nations (DN) or industrialized nations (IN)), where to source their components from (DN or IN), and which market to sell to (DN or IN). For this classroom setting, all teams are required to assemble in and source from DN, and sell to IN.

Removing these choices from the equation not only reduces the cognitive load, but also has two other advantages. One, it ensures students are competing against each other in the same market (IN), which makes it more fun and makes the comparison of outcomes across teams more clear. Second, the costs and pollution and energy impacts differ greatly between the DN and IN sources of component parts. By restricting teams to sourcing from the same location, teams are solving the same constrained optimization problem. Thus, the economic and environmental impacts of different decisions across teams are more clear.

Appendix B
Green Business lab (Supplemental) Warm-up Exercise

Manufacturing Team:

1. Person A: Use the **components kit** to make a prototype spheremover using only and exactly **4 red rods, 8 white connectors, and 4 small wheels**. Test it on the test track.
    a. How far did it go (number of lines crossed)? ________
    b. How many spheres did it carry successfully? _______

2. Person B: Use the **component cost comparison table** to determine the total direct (materials) cost of your prototype if you use remanufactured components whenever possible: _________ (make sure you use the costs associated with **DN**)

3. Person B: Use the **energy life cycle table** to determine how many ECUs are consumed in each of the life cyle stages:
    a. Raw Material (DN): _________________
    b. Manufacturing (DN): _________________
    c. Distribution (DN): ____________________
    d. Customer Use (IN): _________________
    e. End-of-Life (IN):______________________
    f. Total: _______________

					Lifecycle Energy Use (ECU)				
Component	**QTY**	**Direct Cost per Unit**	**Total cost (QTY * $)**		**Raw Materials**	**Manu-facturing**	**Distri-bution**	**Use**	**End-of-life**
Red Rod	4	$							
White Connector	8	$							
Small Wheels	4	$							
TOTAL									

Marketing Team

Read through the (1) Customer Preference Market Research Report and the (2) Simulated Company Market Research Report to answer these questions:

4. What is the total number of SphereMovers demanded in your target market **(IN)** this cycle? _______
    a. In Cycle 2? ______
    b. In Cycle 3? ______

5. How many companies are in total are you competing against in your target market **(IN)**?
____
    a. List their names:

6. What is the price range expected to be set by the two simulated companies you are competing against in the industrialized nations target market? $ __________ to $ ___________

7. One quick and dirty way to forecast how many SphereMovers you companies you might sell would be to assume that each company in the market sold the same number of SphereMovers. If that happened, how many would your company sell? (Show work) ______

8. How many points would this prototype earn for **Must-have components (IN)**? ____/ 5
    a. Explain:

9. How many **performance points** would this prototype earn?
    a. Distance: _____/ 5
    b. Capacity (**IN**): _____ / 5

10. Reflection Prompt: What are some strategies you could do in your role at the company to improve the relationship between energy, the economy, and sustainability?

Green Business lab (Supplemental) Warm-up Exercise (Solution)

Manufacturing Team:

1. Person A: Use the **components kit** to make a prototype SphereMover using only and exactly **4 red rods, 8 white connectors, and 4 small wheels**. Test it on the test track.
   a. How far did it go (number of lines crossed)? **varies** [**2 pts if between 1 and 5; 0 otherwise**]
   b. How many spheres did it carry successfully? **varies** [**2 pts if between 0 and 24; 0 otherwise**]

2. Person B: Use the **component cost comparison table** to determine the total direct (materials) cost of your prototype using remanufactured components whenever possible: **$** 763.80 **(Sum A)** (make sure you use the costs associated with **DN**)

3. Person B: Use the **energy life-cycle table** to determine how many ECUs are consumed in each of the life cycle stages:
   a. **Raw Material (DN):** **16.25 ECU or Sum B from table below** **[2 pts]**
   b. **Manufacturing (DN):** **51.50 ECU or Sum C from table below** **[2 pts]**
   c. **Distribution (DN):** **14.40 ECU or Sum D from table below** **[2 pts]**
   d. **Customer Use (IN):** **64.00 ECU or Sum E from table below** **[2 pts]**
   e. **End-of-Life (IN):** **55.00 ECU or Sum F from table below** **[2 pts]**
   f. **Total:** **201.15 ECU Sum of B to F** **[2 pts]**

					Lifecycle Energy Use (ECU)					
Component	**QTY**	**Direct Cost per Unit**	**Total cost**		**Raw Materials DN**	**Manu-Facturing DN**	**Distri-bution (global)**	**Customer Use IN**	**End-Of-life IN**	**TOTAL**
Red Rod	4	**$31.10**	**$124.40**		**0**	**25.00**	**3.20**	**16.00**	**9.60**	
White Connector	8	**$ 65.60**	**$524**		**16.25**	**25.00**	**3.20**	**16.00**	**22.00**	
Small Wheels	4	**$ 28.85**	**$115.40**		**0**	**1.50**	**8.00**	**32.00**	**23.40**	
TOTAL			**$ 763.80 Sum A**		**16.25 Sum B**	**51.50 Sum C**	**14.40 Sum D**	**64.00 Sum E**	**55.00 Sum F**	**201.15 Sum B:F**

Marketing Team

Read through the (1) Customer Preference Market Research Report and the (2) Simulated Company Market Research Report to answer these questions:

4. What is the total number of SphereMovers demanded in your target market **(IN)** this cycle? _**100,000**_ **[2 pts]**

a. In Cycle 2? _**150,000**_____ **[2 pts]**
b. In Cycle 3? _**200,000**_____ **[2 pts]**

(see customer preference market research)

5. How many companies are in total are you competing against in your target market **(IN)**? __**4**___ **[2 pts]**
   a. List their names: **Company A, Company B (could be Company B &C or A &C), Eco-sphere, SphereCare (see Sales Forecasting Tool)**

6. What is the price range expected to be set by the two simulated companies you are competing against in the industrialized nations target market? $ __**4,200**___ to $ __**4,999**___ **[2 pts] (see Marketing Decisions page)**

7. One quick and dirty way to forecast how many SphereMovers you companies you might sell would be to assume that each company in the market sold the same number of spheremovers. If that happened, how many would your company sell? (Show work) __**20,000**______ **[2 pts]**
   WORK: Total Demand divided by number of companies in the market: 100,000/5 = 20,000

8. How many points would this prototype earn for **Must-have components (IN)**? __**2**__/ 5 **[2 pts]**
   a. Explain: **The prototype has 4 red rods. The IN market awards only 2 points for having 3-4 must-have red rods. (see customer preference market research)**

9. How many **performance points** would this prototype earn?
   a. Distance: __varies___/ 5 **[2 pts - should be equal to the number of lines crossed that were stated in the first question]**
   b. Capacity (**IN**): __varies___ / 5 **[2 pts - should be points earned based on # of spheres that were stated in the first question, see following table from customer preference market research]**

Points	Industrialized Nations Number of spheres
5	20 or more
4	12 to 19
3	6 to 11
2	3 to 5
1	1 or 2

10. Reflection Prompt: What are some strategies you could do in your role at the company to improve the relationship between energy, the economy, and sustainability? [students must mention at least one piece of relevant information found in the lab materials]

Appendix C: **Final Presentation Template**

Prepare a presentation that discusses the economic, environmental, and community impacts from the life cycle energy footprint of your SphereMover.

(1) Summarize the change in energy use at each life cycle state from cycle 2 to cycle 3 for your prototype

(2) Explain the economic and other incentives within the lab that guided you to achieve the lowest life cycle energy use vehicle that you could

(3) Explain how you balanced the costs of reducing energy-use with profit maximization

(4) Reflect on the lessons learned from the lab in light of GHG reduction goals and policy options.

Table 1: SphereMover Model Life-cycle Energy Use Summary

Life-cycle Stage	**Energy Units Cycle2**	**% of Total**	**Energy Units Cycle3**	**% change**
1. Raw Materials				
2. Manufacturing				
3. Assembly & Dist				
4. Customer Use				
5. End-of-Life				
TOTAL		100%		

Table 2: SphereMover Model Economic Trade-offs of Life Cycle Innovation Decisions

Life-cycle Stage	Option A	Option B	Option C	Option D
1. Raw Materials				
2. Manufacturing				
3. Assembly & Dist				
4. Customer Use				
5. End-of-Life				