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Using an Agent-Based Modeling Simulation and Game to Teach Socio-Scientific Topics

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Abstract. In our modern world, where science, technology and society are tightly interwoven, it is essential that all students be able to evaluate scientific evidence and make informed decisions. Energy Choices, an agent-based simulation with a multiplayer game interface, was developed as a learning tool that models the interdependencies between the energy choices that are made, growth in local economies, and climate change on a global scale. This paper presents the results of pilot testing Energy Choices in two different settings, using two different modes of delivery.

Keywords: serious games, multi-player games for learning, agent-based simulation, climate change, general science education.

1 Introduction

Today's citizens, who are operating in a world where science, technology and society are tightly interwoven, need to be able to evaluate scientific evidence and make informed decisions based on available data. This is especially true for socio-scientific issues – such as energy consumption, diet, and health care – where consumers' choices can collectively have a major impact both on themselves and their world.

We developed Energy Choices, an agent-based simulation with a multi-player game-like interface, to facilitate this type of learning. In simulation mode, autonomous agents (with initial states and behaviors determined by real data) represent countries choosing how to spend their GDP. In game mode, each student gets to play a world leader, taking control over the choices made by these agents to achieve two seemingly conflicting goals: to grow their local economy, while reducing their carbon footprint. Supplemented by course materials created for this project, Energy Choices teaches students to predict and mitigate the effects of their collective choices. Because Energy Choices is reality-based, the decisions that students make, and the consequences of these decisions, can be compared with scenario-based projections that serve as inputs to the General Circulation Models on which global policy decisions are based. In terms of complexity, this places Energy Choices somewhere between case-based teaching [1] and the recent "democratization" attempt of the NSF-supported General Circulation Model [2].

The contribution of this paper is to present the results of pilot testing Energy Choices at two different institutions of higher education, using two different approaches. In the remainder of this section, we review the literature supporting this approach to learning. In the next section, we provide an overview of Energy Choices. Following that, we discuss the results of our pilot studies. We conclude with lessons learned and future directions for research and development.

1.1 Learning Science

Our national science education standards recommend that, "All students should develop understanding of science and technology in local, national and global challenges" [3]. Because of this, there has been a growing focus on the combined context of science, technology, and society, stressing the importance of science in the lives of 21st century citizens [4]. Within this context, the Nature of Science (NoS) has emerged as not only a fundamental component of science education but also an interdisciplinary area of inquiry that draws its intellectual input from both the natural sciences and the social sciences [5].

Educators widely recognize that active learning is important to "meaning making" among learners [6]. Yet traditional approaches to science education do a poor job of integrating the learning of content (knowledge, facts) with the inquiry process (how to "do" science). As a result, too many students come to believe that learning science means memorizing facts and that science is something that one gets right or wrong. They need to be shown that scientific inquiry necessarily involves human imagination and inference, and is therefore socially and culturally embedded [5].

Another major stumbling block for learners of science can be their own set of preconceptions [7]. Based on everyday experiences, these preconceptions are reasonable; yet they are often at variance with the laws of science. Students (and the general public) often have difficulty grasping the abstract concepts that would enable them to make connections between their personal behavior and collective societal behavior [8]. These misconceptions can lead to a range of responses to global warming, from apocalyptic alarmism on the one hand to dismissal of the concept as a hoax [9].

A focus on NoS recognizes that scientific knowledge is a dynamic, powerful way to understand aspects of the world, and is therefore constantly evolving, based on observations. It also allows students to connect to the subject matter on an emotional as well as cognitive level, which is particularly important in areas with social impact, such as environmental studies [10]. The global environment, with its complex, real-world problems, is a natural scientific area for this type of inquiry based study. Environmental education typically looks at the qualitative nature of the learning experience and student perceptions, as well as the more quantifiable learning outcomes [11]. Emphasis in such classes can therefore be placed on critical thinking, problem solving, and decision making.

According to the National Research Council's national science education standards, what we need is an integrated approach that 1) addresses students preconceptions, creating conditions in which students can undergo important changes in their thinking; 2) actively engages students in the process of "doing" science within a classroom community that simulates important roles in the science community; and 3) encourages meta-cognitive reflection, teaching student to question the obvious, develop models, and test rigorously [3]. Science can be made more meaningful by using an inductive educational approach [1] and focusing on socio-scientific issues [4]. This approach attempts to build a framework in which the nature of science, classroom discourse, cultural issues, and case-based studies are woven together in a way that makes science more real, and understandable, to the average person.

1.2 Educational Simulations and Games

Today's students, as part of the “net generation”, grew up with video games and the Internet [12]. Because of this, researchers and educators are eager to tap into the power of simulations and games so they can take whatever makes games for entertainment so popular and apply it to learning games [13, 14, 15]. Gee [16] notes that the best games have an immersive quality that encourages players to develop a thorough understanding of the domain of that game. His principles for designing effective learning games therefore have a strong emphasis on semiotics, in the domain of the game as well as the topic being learned. Shaffer points out that “fun” is not the most important aspect of a game; in fact, what is truly important are the roles that the players take on, and the rules that they must follow [17].

Simulations and games are useful not only for motivating students, but also for confronting students with their misconceptions, while offering alternatives [18]. Agent-based modeling (ABM) can simulate complex systems ranging from the social sciences [19] to the physical sciences [20]. In most cases, minimal interaction is allowed, with the simulation built primarily on a combination of real world data and assumptions about behavior. Another promising aspect of games is the opportunity for collaborative learning, particularly in multi-player games.

Multiplayer games can be useful learning tools in that they encourage collaborative learning [21], which has been shown to increase the learning effect in serious games [22]. Multiplayer games with open-ended goals can also support an inquiry-based approach to learning about intricate interrelationships in complex systems [15]. This is particularly useful for socio-scientific topics – such as the relationship of energy choices to economics and climate change – where the interactions of people are just as important in the system as the principles of science.

It is not surprising that several other games for learning environmental science are currently available. For example, role-playing games in the classroom can give students an engaging way to explore different sides of the environmental issues [23, 24, 25]. MIT's Environmental Detectives game takes players out into the field with an augmented reality game that makes use of portable PDAs [26]. Brownfield Action is a computer simulation that allows students to investigate a suspected contaminated land site [27]. Single-player games – such as Climate Challenge, EnerCities, and Shortfall – enable undergraduate students to explore issues of sustainable development policies at varying levels [28]. Baytak and Land [29] took another approach, getting students to use their reflections on environmental issues to create their own environmental games in Scratch. Most closely aligned to Energy Choices is the Bay Game, an agent-based simulation game developed at University of Virginia, allows participants to play the roles of stakeholders in the Chesapeake Bay Watershed's environment [30]. Yet although these games are useful learning tools, they do not address the complexity inherent in the global community of nations acting autonomously. One notable exception is Buckminster Fuller's World Game in which players "develop their own theory of how to make the total world work successfully for all of humanity" [31].

The Energy Choices game is unique in that it 1) incorporates the intrinsic conflict in all environmental issues: to find the balance between economic development, minimization of inequity and minimization of environmental stress; 2) offers a mix of autonomous agents and players, to prevent skewing of results that can occur if we look at the impact of only one or two countries without considering the majority of the world's population; 3) allows students to play world leaders over an extended period of time, seeing the social and scientific repercussions of their decisions and be able to compare the results with professional models that act as official input to policy makers; and 4) automatically gathers player performance data for evaluation purposes. Although the game strives to be entertaining, we believe that it is most important to retain the testable conformity to the real world.

2 Energy Choices

Energy Choices grew from a computer simulation constructed by one of the co-authors to demonstrate the complex interactions of socio-economic forces, and assist in generating credible scenarios for global sustainable development that are directly dependent on decisions made by the participants [32]. The simulation is not aimed at predicting the future but at revealing relationships between individual decision-making and collective outcomes.

The essential role that both socio-economic human factors and the science of the physical environment play in modeling future climate changes makes the issue very complex. A methodology known by the acronym of IPAT simplifies the issue by presenting the increase in greenhouse gasses as a product of factors where the dimensions of the terms cancel out. Here, I stands for *Impact*, P for *Population*, A for *Affluence* and T for *Technology*. IPAT is a useful model for illustrating how changes in various forces can affect the environment. Although this model is too general to be used for forecasting or predictive purposes, it is easily understood by both natural scientists and social scientists, and is therefore useful for presenting principle ideas to freshmen in college [33].

For emission of CO_2, the identity can take the following form:

$$\frac{CO_2}{Year} = Population\left(\frac{GDP}{Population}\right)\left(\frac{Energy}{GDP}\right)\left(\frac{FossilFuels}{Energy}\right)\left(\frac{CO_2}{FossilFuels}\right) \tag{1}$$

The *Impact* here is environmental (CO_2/Year), and *Affluence* is measured by Gross Domestic Product (GDP) per capita (GDP/Population). In the remaining *Technology* terms, Energy/GDP describes what is often referred to as Energy Intensity. For a given population change, the policy goals are to minimize CO_2 production while at the same time maximizing the GDP per capita.

Energy Choices was developed as an agent-based simulation that uses IPAT to model the various forces at play. Agents in the simulation represent the 25 most populous countries in the world, corresponding to more than 75% of the world's population and ranging from very poor third-world countries to some of the most affluent countries in the world. Initial data for the simulation comes from the World Bank open database and International Energy Agency statistics. Details on the algorithms driving the simulation are provided in [34].

Building on this simulation, we developed a game interface to enable interactive changes to the scenarios. The game architecture is illustrated in figure 1. The simulation, implemented in Java, runs on a server. Defined within this simulation are the Entities (countries and world), Agents (defining actions and interactions), Managers (enabling parameter changes in the behaviors), and Value Objects (VO, defining communications with the game). Data Access Objects (DAO) handle MySQL database transactions, which record initial values, choices made by the players, and all intermediate states of the simulation/game. Java servlets facilitate communication via XML messages with two client applications: a Game Interface, and an Instructor Interface. Both of these have been implemented in Adobe Flash, and can run in any computer's web browser that has the FlashPlayer.

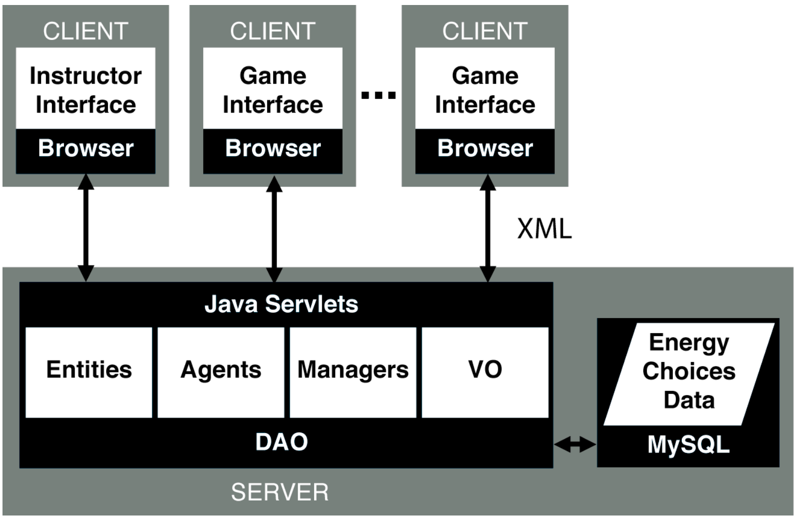

Fig. 1. Architecture for Energy Choices.

The instructor/administrator interface is used to initiate and pause the simulation, as well as view its progress. Initial settings include default behaviors (e.g. desired GDP growth rate, and whether to use current fuel mixes or just use the cheapest option) and whether or not to implement global policy (Cap & Trade). Iteration cycles – where each iteration represents a year – are timed so that the gameplay is fast-paced and exciting, but not so fast that players don't have time to react. Once the game is set up, the administrator may choose to either run it as a simulation, or wait for players to sign on so it can be used as a multi-player game.

Figure 2 shows a snapshot of Energy Choices front-end when it is run as a simulation. In this case, the simulation was set up as a greedy scenario, so that all countries try to achieve a 10% GDP growth rate and all purchase the cheapest fuel. Although this initially leads to great prosperity for many of the countries, it also quickly bankrupts the poorer countries. Furthermore, the high demand for fossil fuels quickly forces their prices upward. At the same time, the carbon dioxide emitted drives the global temperature up more than 3°C after only 30 years, an outcome with dire consequences for our global ecosystems [35]. In contrast, using a Cap & Trade strategy enables more countries to survive economically, with the richest countries doing just as well as in the previous scenario; and the average global temperature only goes up less than 2°C in the same period of time.

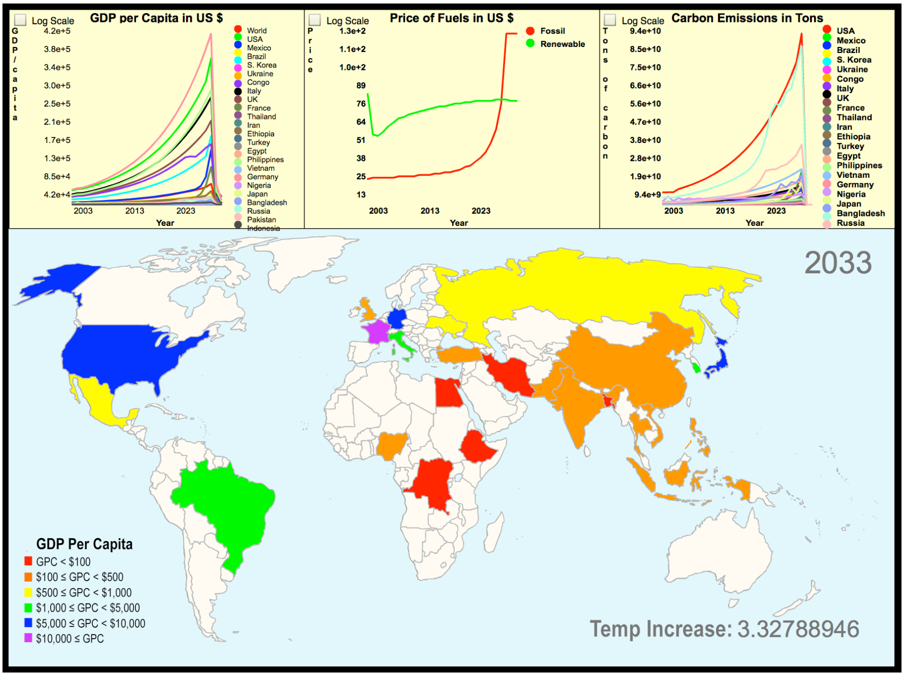

Fig. 2. Energy Choices run as a simulation using a greedy scenario, after 30 years.

Although the simulation by itself is a useful learning tool, we wanted to further enhance the experience by introducing aspects of collaboration, cooperation, and group learning. We chose to do this by creating a multi-player game version of the simulation, where players interact with the system (and each other) to achieve their goals [21, 22]. The goal of each player is to improve the finances of their citizens (especially in the poorer countries) while reducing their carbon emissions (especially in the wealthier countries). By having students take on the roles of different countries – which have vastly different circumstances to begin with – and getting them to talk about what is happening during the game, students are made more aware that there is no simple solution to this dilemma.

When Energy Choices is run as a game, students sign in, select a country, and make choices that impact that country agent's behavior. Figure 3 shows the main game interface. Choices – including what energy to purchase, how to apportion the GDP, and conservation measures – can be made at each iteration of the game/simulation. Players may leave those parameters as they are, or adjust their values. When the simulation/game is running, all 25 agents participate. Behaviors of countries controlled by students will be over-ridden by the choices those students make; any agent that is not selected by a student will simply follow the default autonomous behavior. It is important to have all 25 countries participate, because otherwise the total population represented would be too low, and that would therefore skew the results. Because we use an agent-based simulation, any number of students can play … twenty-five, just one, or none.

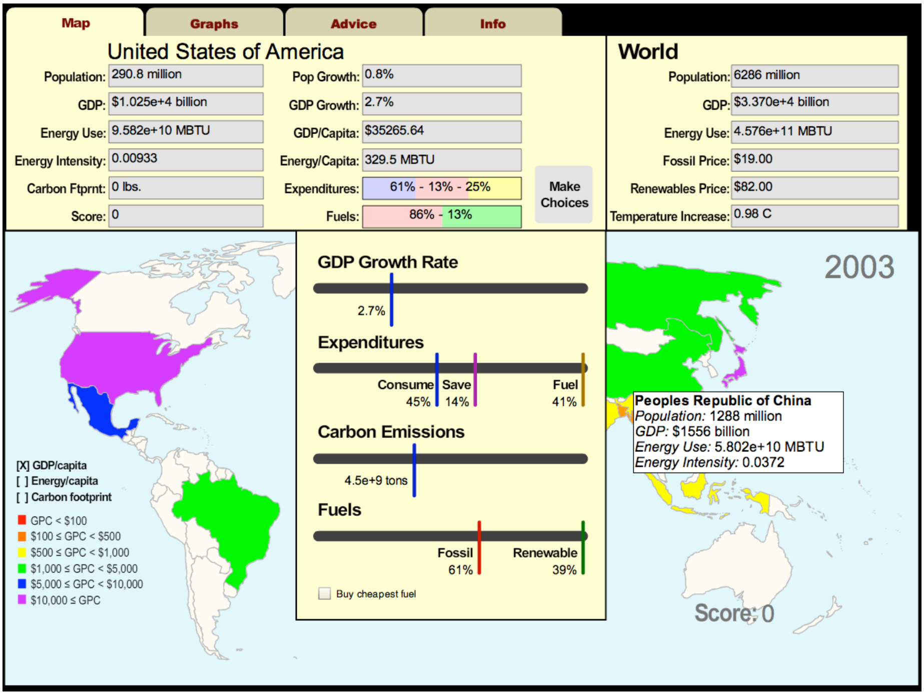

Fig. 3. Player interface for Energy Choices used as a multi-player game.

In game mode, each player acts as an "enlighten despot" who must satisfy the balance between local prosperity and collective sustainability. The impact of climate change is functionalized through the creation of a carbon footprint property, representing how much carbon dioxide each country has emitted as a result of burning fossil fuels. The player's score is therefore based on both growth in consumption per capita and reduction of the carbon footprint. A country can reduce its carbon footprint by either using a larger proportion of renewable energy sources, or reducing its energy intensity (which determines how efficiently the country uses energy to generate GDP). Taking the former option will pay off in the long run by reducing the price of alternative energy and generating more GDP for the amount of energy purchased. The latter option may be achieved by increased savings, which translates to investments in infrastructure.

3 Pilot Studies

Energy Choices was used in two different ways, in two different contexts. First, it was used as a simulation in a general science education course at Brooklyn College, located in New York City. Second, it was used as a multi-player game in a freshman seminar at Stony Brook University, located on Long Island. Learning objectives for Energy Choices are the following:

- understand the environmental and economic impact of energy consumption choices;
- realize that cooperation among all the entities benefits everyone, and that greed leads to the downfall of all;
- learn to reason and draw conclusions based on quantitative information distilled from real and reliable data; and
- encourage reasoned discourse among students as they make science-based decisions, showing that an understanding of science – accompanied by respect for cultural and personal differences – can help us to make moral decisions that benefit all.

3.1 Simulations at Brooklyn College

Energy Choices in a simulation mode is used in two 3-credit courses that are being taught at Brooklyn College. The first is an upper tier, general education course titled "Energy Use and Climate Change" that is being taught every semester, and the second is an Honors College (Macaulay College) seminar that is given to students in the Fall semesters. Both courses are anchored on climate change and on the book "Climate Change: the Fork at the End of Now" [36]. The Macaulay seminar was also anchored on students' investigations of various practices in New York City related to climate change. The end product of the Macaulay seminar is a student construction of a web page that summarizes their research efforts. An example of such an effort is given at http://macaulay.cuny.edu/eportfolios/tomkiewiczs11/course-info/syllabus/. Both courses are now in the process of shifting to a Team Based Learning mode [37] that offers unique opportunity to incorporate student consultation in changing strategy in mid game.

The simulation was designed to achieve two objectives. First, address some of the issues associated with denying climate change. Second, justify the need for transfer of resources from rich countries to poor countries as part of a global strategy to combat climate change. Both issues are difficult to account for objectively to populations of undergraduate students.

Arguably, deniers (or skeptics) can be divided into three categories[1]:

(1) Deniers of the science. This group basically states that the science is wrong, so there is no need to do anything to counter the impact that scientists predict. Their general tactic is to disagree with some specific piece of the data and then use that as "proof" that the science is wrong in its entirety.

(2) The fatalists. This group fully agrees with both the science and its predicted impact, but believes that since the task of preventing it is so enormous as to be practically undoable, they might as well enjoy life for as long as it lasts. Unfortunately, many in this group are good scientists.

(3) The NIMBY ("not in my back yard") group. Again, this group believes the science and the predicted impact, but does not want to take responsibility for the steps necessary to mitigate the problem, preferring to pass the task off onto others.

The common denominator in all three groups is the unwillingness to do anything to reduce the likelihood of the predicted impact.

The Energy Choices simulation was designed to convince the fatalists that it is possible to change the present spectrum of energy use to a much more sustainable mix without giving up on the desire for a prosperous world. This is being done through a policy such as cap and trade with the parameters adjusted by a collective decision of the students. The change in policy will also require that the cap and trade revenues will be used to subsidize the purchase of sustainable energy sources by the poor countries. The distribution of the subsidies is based on the GDP/Capita of the countries.

This outcome is also helpful in explaining why resources need to be shifted from the rich countries to the poor countries. What helped to address this issue are the reports compiled by the National Intelligence Council [38] which outline the security challenges in an unequal world.

3.2 Games at Stony Brook University

At Stony Brook University, Energy Choices was played 3 different days (twice each day) in a 1-credit freshman seminar during the spring 2013 semester. The text for the course was Climate Change (Tomkiewicz). We wanted to know how different ways of interacting with the game could influence student interest as well as learning. To learn this, we ran the following experiments.

Knowing Your Opponents. Half of the students were told who was playing what country, and the other half weren't. In the end, they were asked whether knowing/not knowing who their opponents were made the game more fun, made them want to do better, and made the game more interesting. Table 1 shows the results.

Overwhelmingly, students thought it was more fun to know who was controlling what country in the game. However, it did not necessarily make them play better; most students mentioned that they wanted to do well whether people knew what their

[1] These categories are described in greater detail on the co-author's blog at http://climatechangefork.blog.brooklyn.edu/2012/09/03/three-shades-of-deniers/.

score was or not. Knowing who was controlling what country did not make the outcomes more interesting, either; several students pointed out that it was more interesting to see what countries (not players) were doing better.

Table 1. Does knowing who controls what country…

	Yes	No	Total
… make the game more fun?	11	1	12
… motivate you to do better?	4	8	12
… make the outcomes more interesting?	5	7	12

Game Strategies. After giving students an overview of the game, we asked them what strategies would be most important to achieving a high score (based on growing GDP/capita and reducing carbon emissions). We asked them the same questions again after they had played 6 times. Table 2 compares students' responses to both questionnaires; responses the second time around are in parentheses. Table 3 summarizes changes in students' responses. Apparently most students did not change their view of how important it is to use renewable fuels; at the same time, many students came, over time, to recognize that growing the economy in the game required using lots of fuel and building infrastructure. Students also came to recognize the global benefits of sharing the wealth.

Table 2. Students perceptions of what strategies would work best students, measured before and after playing Energy Choices

Strategy	1 - Not Important	2	3	4	5 – Very Important	N
Grow GDP	(1)	1 (2)	5 (2)	5 (4)	3 (5)	14 (14)
Share wealth	2 (2)	3 (3)	5 (6)	2 (4)	2	14 (15)
Minimize CO_2	(2)	2 (1)	1 (2)	5 (6)	6 (4)	14 (15)
More renewables				9 (8)	5 (7)	14 (15)
Use cheapest fuels	6 (3)	3 (7)	3 (3)	2 (1)	(1)	14 (15)
Buy lots of fuel	2 (1)	8 (4)	4 (4)	(4)	(2)	14 (15)
Build infrastructure	1	1	5 (8)	2 (5)	5 (2)	14 (15)

Table 3. Change for respondents who answered both surveys

Strategy	Decrease in importance	Same importance	Increase in importance	N
Grow GDP	2	4	5	11
Share wealth	2	5	5	12
Minimize CO_2 emissions	3	6	3	12
Use more renewable fuels	2	8	2	12
Use cheapest fuels	3	4	5	12
Buy lots of fuel	2	3	7	12
Build infrastructure	4	2	6	12

Visualizations. After playing Energy Choices, students were asked to look at a visualization of information gathered by the Energy Choices system. They looked at the data for two games that they played, and two simulations that had the same setup as their games but then ran autonomously (i.e. without player input). We then asked them whether they enjoyed visualizing the games they played or the simulations more. Overwhelmingly, the students preferred looking at the visualizations of what they had done. As one student pointed out, the visualizations of the games "showed more variation and showed us how we controlled the outcome".

Students were then asked to reflect on how they could do better in the game, based on observations gleaned from the visualization. Tables 1 and 2 show the results, comparing the final outcomes of the simulations (with no student input, using World Bank baselines) to games played in subsequent weeks (day #1 and #2) and a final game played after looking at the visualization (day #3). In these tables, total GDP and population represent the total for all 25 countries; GDP/capita is the average amount of GDP earned by each person; GDP/MBtu represents how much GDP is generated per unit (mega-Btus) of energy; and score is based on raising GDP/capita and lowering carbon output. Global temperature increase is above the base level at the start of the industrial age.

In Table 4 we see a "greedy" scenario, where countries try to grow their economies rapidly by always buying the cheapest fuel. After students looked at the visualizations, they were able to grow their economies (and their scores) significantly. However, at the same time, they also raised the global temperature to an unacceptable level.

Table 4. Changes in outcomes in games using the greedy scenario

Properties	Simulation	Day #1	Day #2	Day #3
Total GDP	$1.3e+14	$1.5e14	$1.2e14	$2.0e37
Total Population	7.75e9	7.74e9	7.75e9	4.76e9
Average GDP/capita	$16,122	$19,556	$15,901	$4.2e27
Average GDP/MBtu	$67	$92	$75	$83
Average Score	260087	161708	243618	2.72e28
Global temperature increase	2.19°	1.88°	2.08°	19.76°

In Table 5 we see a scenario where a "cap and trade" policy is imposed. Here, countries pay a fee for every ton of carbon dioxide emitted. The collected money from the fees then goes to subsidize countries with lower than average GDP per capita. After students looked at the visualizations, they were able to significantly lower the rise in global temperature. At the same time, they were able to generate much more GDP per unit of fuel.

Table 5. Changes in outcomes in games using the cap & trade scenario

Properties	Simulation	Day #1	Day #2	Day #3
Total GDP	$2.7e13	$3.2e13	$2.2e15	$1.8e14
Total Population	7.76e9	7.76e9	7.62e9	7.74e9
Average GDP/capita	$3452	$4103	$285,225	$23,431
Average GDP/MBtu	$78	$81	$9	$119
Average Score	-6518	-22689	3228262	130647
Global temperature increase	1.26°	1.16°	4.64°	1.14°

Looking at the visualizations as instructors, we could see that, over the course of several weeks, students had learned how to do better in the game. They also learned that different scenarios called for different strategies.

4 Conclusions

Pilot tests of the Energy Choices simulation and game demonstrate the feasibility of using Energy Choices as a learning tool in the classroom. Students do appear to be more engaged when they get to control the choices made by countries, and compare how they did to the achievements of their classmates. Furthermore, we found that students could learn even more about how the game works by examining visualizations of the game they played after the fact. We plan to follow this up with subsequent studies that compare learning with Energy Choices to learning without it.

We are currently updating Energy Choices to incorporate more choices, in terms of what fuels are purchased (e.g. coal, oil, and gas) and how savings are invested in infrastructure (e.g. education, transportation, and communications). We are also improving the gameplay mechanics to better motivate the students while providing better feedback mechanisms so that they can learn more from the experience.

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