Designing Entertaining Educational Games Using Procedural Rhetoric: A Case Study

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Abstract

In the paper we describe the design and development of a video game about sustainable energy use that effectively unites fun with learning. We also present results from an initial study of the educational impact of the game. Many educational games do not properly translate knowledge, facts, and lessons into the language of games. This results in games that are often neither engaging nor educational. Our approach differs by using game mechanics to express the educational content. The design combines the fantasy elements and game play conventions of the real-time strategy (RTS) genre with numbers, resources and situations based on research about real-world energy production and use. The result is a game in which the player learns about energy use simply by trying to overcome the game's challenges. We demonstrate that effective and engaging learning games can be developed as long as sound game design principles are used. Results from a combined quantitative/qualitative study show that players enjoyed the game, learned new things and became more interested in the topic of energy use. This paper will highlight key aspects of the design that we believe contributed towards making the game fun as well as educational. The game also presents a model for translating real-world topics into game mechanics using the language of procedural rhetoric. The real world is ripe with problems and situations that could inspire interesting game mechanics and provide new creative ideas for educational and traditional game designers.

CR Categories: K.3.1 [Computers and Education]: Computer Uses in Education—Computer-assisted Instruction; I.6.8 [Simulation and Modeling]: Types of Simulation—Gaming K.8.0 [Personal Computing]: General—Games

Keywords: Serious games, Educational games, Simulation games, Game design, Procedural rhetoric, Energy, Environment

1 Purpose

This paper describes the design and development of a real-time strategy game, *Super Energy Apocalypse*, that teaches players about sustainable energy use and the intricacies of an energy economy. The game uses real-world data about the U.S. energy economy to create a model for the game's economy. The goal of the game is to help players understand the relationship between energy production, natural resources, transportation, fuel, power plants, the economy and pollution. None of these issues can be taken in isolation – they can only be truly understood as a systemic whole. For instance, ethanol-based fuel is often promoted as being better because of its lower emissions. However the production of ethanol results in a negative energy balance and even consumes fossil fuels [Pimentel and Patzek 2005]. This is the sort of lesson that could be effectively demonstrated through interactive game play.

Many educational games appear to be neither entertaining nor particularly successful in teaching players. These games suffer from two fundamental flaws: a) the people who design them often do not have traditional game design experience [Van Eck 2006] and b) they do not properly translate knowledge, facts and lessons into the language of games, namely mechanics, rules, rewards and feedback [Jenkins and Hinrichs 2003]. Examples of games that avoid these problems and are still engaging and educational include Peacemaker [ImpactGames 2007], The Redistricting Game [Swain 2007b] and A Force More Powerful [International Center on Nonviolent Conflict and York Zimmerman, Inc. 2006].

Similar to the games mentioned above, our approach uses game mechanics to express educational content. We show that effective and engaging learning games can be developed as long as the rules and mechanics allow the educational message to emerge from gameplay [Gee 2006]. We highlight key aspects of the design that we believe contributed towards making the game fun as well as educational and present results from a combined quantitative/qualitative study of the game.

2 Theoretical Framework

The real-world energy economy represents a fairly complex and ill-structured knowledge domain. Spiro notes that this type of content is better conveyed using "nonlinear and multidimensional learning and instruction" [Spiro and Jehng 1990], which computer games embody. Jonassen argues that Spiro's Cognitive Flexibility Theory [Spiro et al. 1988] "provides an effective model for designing and developing computer-based instruction to support advanced knowledge acquisition which is required ... to solve real world problems" [Jonassen 1992]. We can conclude that computer games would be well suited for teaching players about the intricacies of the real-world energy economy.

Games give players a mental obstacle course with opportunities for success or failure at every turn. Failure leads to an urge to try again, eventually leading to success. With each success comes a feeling of triumph, providing motivation for the next challenge. The cycle continues until the player masters the game. Raph Koster notes that the joy that we receive from games ("fun") is tied to the reward system the brain uses to learn [Koster 2005]. In other words, fun is quite often the very evidence of learning. The game becomes a formal system of challenges to stretch the brain, coupled with rewards to encourage the player to seek out the next learning high. In this sense, all games are educational - at a minimum, a game must teach a player how to play the game. Games can thus be used as powerful learning tools that harness the brain's exploratory reward system to induce learning and critical thinking.

Although games and the mechanism of play have been used as ve-

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hicles for learning and understanding since the beginning of human civilization [Abt 1970], the advent of electronic multimedia led to the rise of explicitly educational video games. The most widespread manifestation of this is in the form of "edutainment," the fusion of "education" and "entertainment." Often edutainment takes the form of multimedia packages that mix facts and/or quizzes into a simple game. This approach is largely ineffective as the game mechanics have nothing to do with the learning material [Jenkins and Hinrichs 2003]. Edutainment software, instead of harnessing the power of games for learning, are often nothing more than "boring games [with] drill-and-kill learning" [Van Eck 2006]. Attaching a standard game mechanic to a simple learning goal is slightly more effective, as demonstrated by Davidson & Associates Math Blaster Episode I: In Search of Spot [Davidson & Associates 1994].

The emerging field of "serious games" seeks to move beyond the simplistic approach of edutainment by building on learning principles implicit in well-designed games [Gee 2003]. The goal is to develop games that "have an explicitly and carefully thought-out educational purpose and are not intended to be played primarily for amusement" [Abt 1970]. However, for a designer of serious games, teaching the player interesting and valuable things through gameplay can and should work hand-in-hand with making that gameplay as much fun as possible. Such a designer is not practicing a different discipline than a traditional game designer, because a serious game cannot be successful unless it builds on a solid foundation of fun.

While "fun" is an important goal for serious game designers, there are no clear guidelines on how to achieve that goal. Studies of gaming environments and their associations with psychological need satisfactions have attempted to provide a more differentiated understanding of what makes games "fun" [Ryan et al. 2006]. Ryan and colleagues found that game features that increase perceptions of autonomy and competence enhance game enjoyment in solitary game play. They suggest that autonomy can be enhanced by "game designs that provide considerable flexibility over movement and strategies" and perceived competence would be enhanced when "game controls are intuitive and readily mastered, and tasks within the game provide ongoing optimal challenges and opportunities for positive feedback." In related work, Lazarro identified four "Fun Keys" that create games' four most important emotions: hard fun (*fiero* – in the moment personal triumph over adversity), easy fun (curiosity), serious fun (relaxation and excitement) and people fun (amusement) [Lazzaro 2004]. She further observes that best selling games offer at least three of the four "Fun Keys".

Procedural rhetoric, a term coined by Ian Bogost [Bogost 2007], provides a relatively new framework for designing educational games. The term refers to "an argument made by means of a computer model" [Bogost 2009]. Examples of games that use this approach include *September 12th*, a game meant to argue against American-style military intervention as a response to terrorism [Frasca 2003], and *Debt Ski*, a game intended to highlight the dangers of excessive debt and destructive financial behavior [Persuasive Games 2009]. Drawing analogies to verbal and visual rhetoric, Bogost defines procedural rhetoric as "the practice of using processes persuasively" [Bogost 2008]. Using this framework, the game designer does not just create an interactive simulation for the player, but specifically infuses it with gameplay rules (i.e. procedures) that form a compelling argument. The rules could be designed to present a particular viewpoint or they could simply model known and widely accepted facts. Using the latter approach, a game that models the real-world energy economy could thus be used to make an argument about energy production and use and its effect on the environment. Players would then learn about these issues simply by playing the game.

3 Game Design and Implementation

The work of Koster and Bogost leads us to conclude that procedural rhetoric is the tinder for learning and fun provides the spark. Our game design is primarily driven by this philosophy. A procedural structure also allows the game to "respond dynamically to [the player's] choices without constraining or anticipating them" thereby enhancing the psychological need of autonomy [Ryan et al. 2006].

Following the literature on best practices for designing games with a social theme [Swain 2007a], the first step was to define the purpose of the game and the intended learning objectives. This is outlined below followed by a set of design principles that guided the development of the game and a description of the game itself.

3.1 Learning Objectives

Our goal was to create a real-time strategy game that drew its economic features from the real world energy economy. This would provide the game with interesting subject matter and mechanics (fun) as well as useful lessons and facts for the player to absorb (learning). For example, coal is incredibly powerful, but pollutes terribly. Wind is clean, but has low output and varies with the weather. Those are facts easily implemented in a game. Our objective was to create a problem for the player to solve that mirrors real-world challenges. The player would have to strike the right balance between production and cleanliness, while simultaneously conserving resources. In so doing, we expect players to:

a) Learn the differences between power plant types in terms of fuel input, power output, and emissions.
b) Learn the pros and cons of different fuels for vehicles.
c) Understand how renewable and non-renewable resources are used and transformed.
d) Understand how each part of an energy economy affects the entire whole.

3.2 Design Guidelines

1. All aspects of the game's energy economy must be based on research. However, conceptual accuracy is desired, not literal precision.
2. The player should be required to produce (and therefore pollute). This forces the player to experience the problem in order to learn how to solve it.
3. Tasks not directly related to energy economy (such as combat) are allowed as long as they do not distract from understanding of the energy economy.
4. Matter may be transformed into energy or another form of matter, but it may not be destroyed. In many games, an object can be completely and totally removed from the game simply by blowing it up. Ernest Adams refers to this cliché as "neat, tidy explosions" [Adams 1998]. In addition to misrepresenting the true nature of violence, this violates the law of conservation of mass. If a building or an enemy is destroyed, it produces garbage that must be cleared. The player will not be able to "delete" something he does not want – he will be forced to deal with his garbage, just like in real life.
5. In-game objects should represent real-world counterparts, but not necessarily on a one-to-one ratio. One game vehicle can represent an entire fleet of real vehicles, and one game day can represent a year of real time.
6. There should be no dominant strategy and no economic tool should be a "silver bullet" for the player's problems. A feature

Figure 1: *"Zombies" invading by night*

can be "useless" or "underpowered" as long as this is the result of implementing real-world research.

7. Fantasy situations are allowed so long as they contribute to the game's rhetoric and are clearly understood as fantasy situations.

3.3 Game Overview

The player finds herself in a post-apocalyptic world teeming with monsters. At the center is a fortress that must be protected. Surrounding the map is wasteland, the home of "zombies." The game is limited to a single, non-scrolling map and is split into two phases during which the player focuses exclusively on either economics or combat. This design avoids the frantic micro-management that is common in many RTS games that require the player to simultaneously juggle exploration, economy and combat. During the day, the player builds up her economy and tries to minimize her pollution. When night falls, zombies try to destroy the player's buildings (Figure 1). The player has to produce enough resources to survive, but the zombies will feed on the player's waste (Principle 1). The daytime phase lets the player try out an economic strategy, and the night-time phase will test how well it works. If the player produced lots of resources and little pollution, she will have plenty of ammunition to use against weak, easily-destroyed zombies. If the player produced few resources and lots of pollution, she will have little to defend herself against pollution-fueled super zombies.

Defending against zombies is the carrot that motivates the player to focus on evolving an effective energy production strategy (Principle 7). The zombies in the game are a metaphor for the harmful effects of pollution arising from human activities. The choice of the fantasy setting is supported by Koster's observation that players are less affected by the theme than the underlying mechanics in terms of what they learn [Koster 2005]. In terms of Lazzaro's four "Fun Keys" [Lazzaro 2004], our game attempts to offer "serious fun", "people fun" and "easy fun".

3.3.1 Defense

To protect her fortress the player places automated defensive turrets that attack enemies as soon as they come into range. Four different turrets are available; each consumes a different resource and provides a different attack (Figure 2). The level design ensures that no single choice is appropriate for all situations (Principle 6).

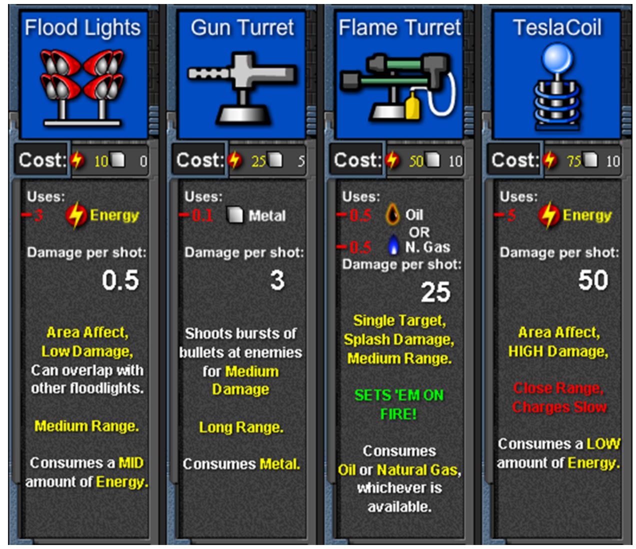

Figure 2: *Defensive buildings*

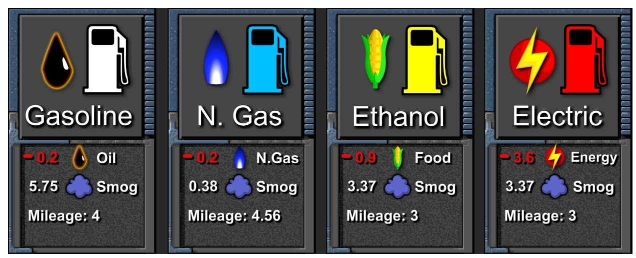

Figure 3: *Fuel options for trucks*

3.3.2 Garbage

Most game objects produce garbage and zombies turn into garbage when they die (Principle 4). Other zombies will eat this garbage and become stronger. To clean up, the player must build garbage trucks that run on gasoline, natural gas, electricity or ethanol (Figure 3). Garbage trucks run automatically, collecting garbage and depositing it into a landfill. All vehicles in the game are governed by a model based on real-world fuel usage, with each in-game truck representing an entire fleet of real-world vehicles (Principles 1 & 5). Landfill placement is a key strategic choice for the player. Placing landfills far away from garbage sources results in long trips for trucks, increasing fuel consumption and leaving garbage on the map for a longer amount of time. However, placing landfills too close to the front lines makes them a target for zombies. If a landfill is destroyed, all the garbage spills out, creating a feast for the zombies. The player should quickly learn that cleaning up waste is essential for survival (Principles 1, 3 & 7).

3.3.3 Power plants

Almost everything the player does requires energy, which is produced by 6 types of power plants, all based on real-world data, and intended to reflect the relative cost-to-energy output ratio of each facility (Principle 1). However one in-game facility does not correspond to one real world facility (Principle 5). Each type of power plant has different pros and cons (Figure 4). The player will have to suit her power choices to the varying situations in each level (Principle 6).

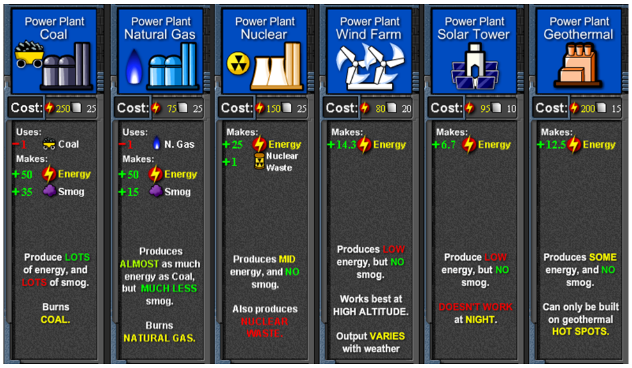

Figure 4: *Power plants*

Figure 5: *Farms produce food for sustenance.*

3.3.4 Supplying the base

Most of the player's buildings consume both energy and food. Buildings require energy to function and food to stay "healthy". It costs energy, and usually metal, to build or repair buildings. Metal for construction and fuel for power plants can be produced by mines and wells, which may only be placed on specific resource-rich areas of the map. Mines and wells produce both resources and garbage, and over the course of time they will run dry. Food can be produced by farms, which consume energy and produce garbage as well as smog (Figure 5). This serves to regulate the player's growth: more buildings require more food, which requires more farms. This requires more energy and garbage trucks which in turn requires more power plants and fuel. Uncontrolled growth will eventually lead to resource scarcity and smog accumulation.

3.3.5 Air pollution

"Smog" is the other form of pollution in the game, which abstractly represents all air pollutants. Smog is particularly dangerous because every 100 units of smog causes all incoming zombies to enter with an extra level of strength. There are no units that "reduce" smog – the only way to lower existing smog levels is to produce less and wait for the atmosphere to stabilize. This can be done by disabling high-emission facilities and vehicles, and/or upgrading them.

Figure 6 shows a screen shot demonstrating several features of the game. Data for the simulation underlying the game was obtained from various sources including the World Nuclear Association [World Nuclear Association 2009], the U.S. Department of Energy [Energy Information Administration 2009; Geothermal Energy Association 2005], power, utility and mining companies [Lower Colorado River Authority 2009; Xcel Energy 2009; Cielo Wind Power 2009; Alcoa Inc. 2009] and press reports [Broehl 2006; Thomas 2007; Public Citizen Inc. 2005].

Figure 6: *Night scene showing farms, landfills, defenses, garbage trucks and zombies.*

4 Evaluation

The game has received critical acclaim in the casual and independent games communities, including winning several contests and awards. As of November 1, 2009, the game generated a combined 3 million plays, of which 2.2 million were unique. Overall the game was successful and quite popular, and feedback through forum posts and emails indicates that the game was definitely fun to play. To determine if the game was successful in meeting our intended learning objectives (Section 3.1), a special evaluation was designed and implemented for a small group of players. A mixed methods approach was used, combining a quantitative test with qualitative responses. A questionnaire was developed for players to take before and after playing the game for a minimum of one hour. Players were asked to rate the energy production levels and the air pollution levels of the six types of power plants represented in the game. They were also asked for their opinion on the best alternative to gasoline, if any. In the qualitative section, players were asked to explain their strategy for winning, what they learned (if anything) and whether they would play the game again. Players were also invited to participate in a post-game focus group session, where they could be probed for deeper understanding.

For the initial study, we were able to recruit 21 participants, five of whom also participated in the subsequent interviews. Participants were recruited through email solicitations for volunteers sent to students in the Computer Science and Visualization departments at Texas A&M University. Participants ranged in age from 18 to 27 years (average 21) and included 5 females and 16 males. None of the participants had played the game before.

5 Results

The answers from the questionnaires were used to calculate pre- and post-game test scores for each participant. The average change for all players was 7.7% on a 13-point test. Seven participants had improvements in the 15-45% range, 5 participants increased by 7.7%, 6 showed no change, and 3 showed a decrease between 7-38%. A paired t-test analysis gave a p value of 0.0626, indicating a 93.74% certainty that the changes in score were not due to random chance. This is just barely short of the standard for a statistically significant p value of 0.05. Approaching significance with such a small sample suggests that a larger sample would likely lead to statistically significant results.

Collectively, participants changed 76 of their answers, of which 45 were from an incorrect choice to a correct one, 23 from a correct to an incorrect one, and 8 from an incorrect choice to another incorrect choice. Participants had the most prior knowledge about coal, wind, and solar plants, showing mostly correct answers for both the air pollution and energy production of these facilities on the initial test. After playing the game, they showed the most improvement in correctly rating the air pollution of natural gas plants and geothermal plants. However, a majority of players rated nuclear power plants as producing high air pollution. This suggests there was a problem with its depiction in game or the framing of the question itself. It is possible that players thought they were assigning a generic pollution rating, noting that nuclear power plants produce hazardous nuclear waste.

Players were more able to correctly rate the relative energy output of power plants after playing the game. Nuclear power saw the most improvement, followed by solar, coal, and wind. The exceptions were natural gas and geothermal. In the case of natural gas, all the players under-estimated the energy output of natural gas power plants. This could be because there is no easy way to compare power plants side-by-side in the game, so players probably never noticed that natural gas plants produce as much as coal in game. For geothermal power, four players changed their answer after playing the game and correctly rated its power output as being "medium". However, three players changed their choice from "low" to "high". Even though they got the answer wrong, they moved in the right direction, indicating that the game showed them that geothermal produced more energy than they initially thought.

Eleven players (52%) made different choices for the best alternative fuel after playing the game. Eight changed their choice to natural gas, 2 chose electricity, and 1 chose ethanol. Of the 10 who didn't change their opinion, 7 chose electric, 1 chose natural gas, 1 chose ethanol, and 1 maintained that gasoline was still the best. Electricity and natural gas were the most popular final choices with 9 votes each, with 2 votes for ethanol and 1 for gasoline.

Many of the lessons that players learned from the game are hard to quantify. Certain players had no increase in score between the two tests, but this does not necessarily mean they learned nothing. The results from the free responses and interviews bore out this hypothesis. Players said that the game was "fun to play", it had "enough depth to keep it interesting", it was "educational, thought provoking" and it was "informational" and "addictive". When asked what they learned, players consistently mentioned subtle and nuanced points about energy use that were built into the game, but not measured on the quantitative test. One player indicated that he learned about how optimal energy choices vary by region, variability of wind power as it depends on the weather, non-availability of solar power at night, and the difference between oil and natural gas. Interestingly, this player had no change in score on the quantitative test. Another player with a zero change in score mentioned that the game opened his eyes to the entire topic of energy use and pollution. One player said that he learned quite a bit, but qualified that by saying he wouldn't have paid as close attention if he hadn't been told at the outset that the game was for educational purposes (indicating that it was based on real science).

6 Conclusions and Significance

The game has been clearly shown to be a fun, popular, and innovative game in its own right that succeeded in garnering both critical acclaim and widespread attention in the world of online games. The results also show that players did in fact learn things from playing the game and that it piqued their interest in sustainable energy use. Qualitative feedback provided useful information about the effectiveness of the game that was otherwise not apparent. Along with quantitative assessments, it is therefore critical to include a qualitative component to the evaluation of educational games.

The game's execution could definitely be improved in many ways, but the foundation it is built on – using fun as the catalyst for the learning process – is solid. Our approach also serves as a model for translating real-world topics into game mechanics. Since there is no "silver bullet" in the real-world energy economy, it stands to reason that there would not be one in an in-game model of the same thing. The key is that most real world systems have natural feedback mechanisms, as well as pros and cons. Aside from a few tweaks here and there, the energy economy section of the game practically designed itself. While this model is useful for serious game designers, the real world is ripe with problems and situations that could easily inspire game mechanics that are interesting for their own sake. For example, a game about building and managing a transportation system for a city could allow players to explore different modes of transportation while trying to balance costs related to construction and maintenance of the infrastructure with congestion, pollution and fuel efficiency. A game based on a real-world agricultural simulator could allow the player to explore the balance between quantity and efficiency vs. quality and sustainability, while incorporating related aspects such as pollution and nutrition. Both games could in fact be designed around a fantasy setting similar to our current game. As our game and the above examples demonstrate, often the question of "game balance" is already present in real-world trade-offs and dilemmas that have no perfect solution. This could provide new creative fuel for traditional games.

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