AC 2008-1446: GREENING THE SUPPLY CHAIN: DEVELOPMENT OF A COMPUTER GAME TO TEACH ENVIRONMENTALLY BENIGN MANUFACTURING

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Greening the Supply Chain: Development of a Computer Game to Teach Environmentally Benign Manufacturing

Abstract
Over the past decade, both massively multiplayer games and simulation games have reached new levels of sophistication and retained enormous mainstream audiences. Developments in digital technology allow new opportunities to engage students in collaborative and active learning. The desire to address complex technological and social issues in an engaged manner inspired the development of a prototype board game created to raise the awareness of environmental issues in engineering. Designed for in-class play by undergraduate and graduate engineering students as well as business students, the game structure is based on team competition of companies in the automobile supply chain; the game objectives are to achieve the highest profit and to achieve the lowest environmental detriment. A new interdisciplinary project funded by NSF has extended the development of the board game to create and assess a networked computer game.

The game is played using stakeholders in the manufacturing supply chain in the automotive industry. In its current non-networked version, six students create a team of three suppliers: materials, parts, and cars. Within this team, two students take on roles for each of the three companies in the supply chain. During each round in the game, each company within the supply chain takes its turn to invest and select among different technologies in three areas for each company: production, storage and waste disposal. There are tradeoffs in investment costs and green values for each technology option, and there is a hierarchy to the innovation options available for each turn. The students work within their team and budget (and within ten rounds of the game) to try to create the most profitable and green supply chain. Students compete with other supply chain teams. Successful game strategy requires both cooperation and competition for players to succeed.

1. Background

This work is based upon development of a board game, entitled Shortfall (previously reported [1-3]), which simulates a simplified supply chain for automobile production. The goal and challenge of playing Shortfall is to learn to maximize profit while minimizing environmental impact. The auto industry manufacturing supply chain allows exploration of relationships among design considerations, supply chain management, environmental issues, research and development, and profitability. Instead of using a lecture format for green manufacturing case studies, the concept of participative group game play is being tested and evaluated for successful learning outcomes. Although the supply chain is simplified, students can experience the ramification of technology selection and processing decisions through a unique educational format.

Initial play tests with the prototype board game appeared to be somewhat overwhelming to understand quickly for many players; after two rounds, players were up to speed, but the game ended after four rounds. There were several boards, dozens of game pieces, work sheets, innovation cards and current event cards. It was necessary to streamline and simplify the game play elements as much as possible, while not oversimplifying any element in order to maintain academic merit.

With the addition of computers to handle all the calculations rather than the players, additional rounds for the game became a reality. The new ten-round game allowed for more flexibility in content and play styles, with long-term planning and goals becoming possible. Strategic planning for technological innovation became possible with the increased number of rounds. This also gave students more exposure to current events (since one event occurs per round) and the educational content. Students can learn facts along multiple dimensions, including: the history of environmentally benign technologies over the past decades; environmental policies and legislation that influence manufacturing in the global economy; current business strategies and technologies used in industry to address environmental burdens; tradeoffs among economic and environmental policies that influence technology; effects of current global events on a sophisticated supply chain and complex engineering system; and team-based decision-making.

The transition to a computer-based platform removed the need for token trading, hand calculations and recordkeeping, and other time consuming elements of the board game. There is also no need for a human game facilitator with the computer-based version, although having a facilitator / instructor present might provide assistance to students who are new to the game or the subject matter. The rounds in the computer-based game are not timed, so the game's progress is not delayed if a group of students need a little bit of extra time to make a decision. When the networking aspect is implemented in later versions, time will again become a factor, but teams could potentially play one turn each day or class period, and the game could progress over several weeks or months. In the networked version, teams will also be able to plan ahead as many turns as they want, though their final decisions won't be "locked in" until all players have committed.

After assessing the comments from the student focus groups that had played the board game [3], the game strategy was redesigned for the computer-based game. Although students generally enjoyed the game and retained knowledge from game play, the issues identified regarding overall game balance, as well as game mechanics and logistics, remained obstacles for effective learning. A redesign allowed these issues to be addressed, and a prototype computer game was created. These design changes were undertaken by two mechanical engineering students as part of a one term undergraduate independent study [4-5].

Section 2 provides a brief overview of the game in its debut digital format, as presented to the players in a handout. Sections 3 through 5 describe the details of the transformation from board game to computer-based game. Section 6 presents preliminary results of the first test play.

2 Creating incentives for game play – a memo from your boss…

"As you know we have recently edged into a new market for our vehicles and have been very successful. However, the competing company and its supply chain are beginning to gain market share. We will need to be more aggressive and assert new strategies to maintain our market dominance. I am giving you, our Auto Division Management Group, control over our supply chain management, and an appropriate budget with which to administer your decision making.

Our supply chain consists of three major stakeholders: our materials production facilities, parts manufacturing factories, and auto assembly plants. Members of your team will be buying raw materials from the market and then fabricating materials to sell to our parts supplier. Parts will be fabricated and then sold to our auto assembly plants, from which finished products will be sold.

One of your team's main responsibilities will be to select investments in innovations throughout the supply chain that are available through our R&D Group. The current R&D team is motivated and very talented. They have been creating innovations that can reduce costs, increase production and capacity, and potentially improve the company's green score in the eyes of our customers. Innovations are expected throughout the supply chain in three categories: Production, Storage and Waste. Innovative technologies in these categories will be vital to us as we expand our market share. I will provide information about technology growth paths that we can pursue.

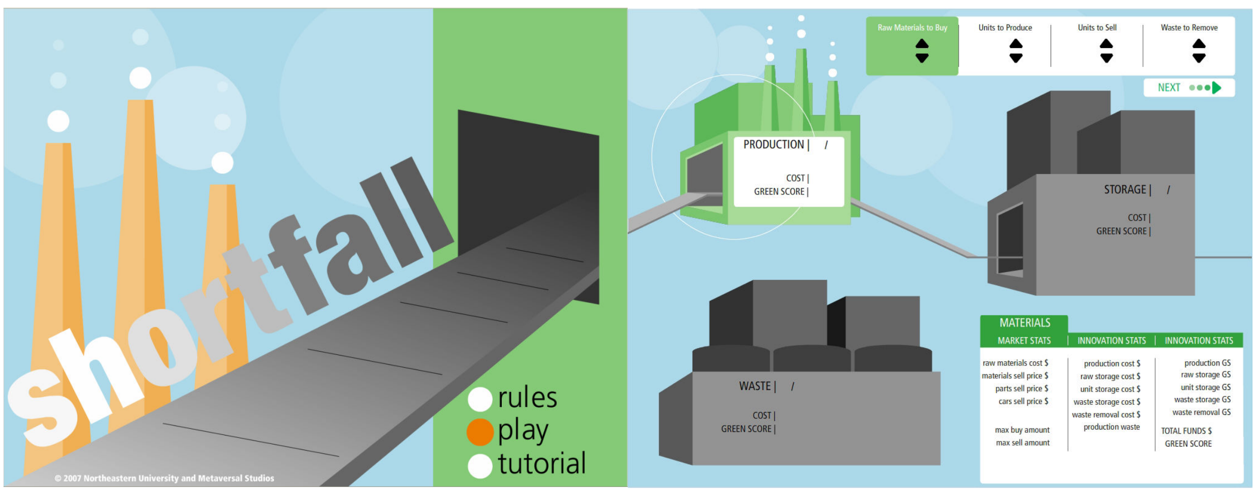

Figure 1 – Prototype screenshot of start page and production facility for a supplier

Each quarter after you choose an innovation in which to invest, your team members will have to then decide how much to buy, produce, store and sell in each tier of the supply chain (as shown in Figure 1). Issues regarding waste disposal must also be addressed. All of these operations will need timely, strategic decisions for purchase of materials, production of units, storage of inventory, sale of completed units, and disposal of waste. Purchase and selling prices and quantities sold are driven by the market, which changes each quarter. Be sure to keep an eye on your budget and plan ahead for market changes.

We are counting on your expertise to keep our business ahead, so please look over the attached information. Keep in mind that current events can ultimately affect our profits. Although recent events have fallen in our favor, events could also affect us negatively, so try to plan your strategies and investments accordingly. Because AutoTech Industries values its customers, communities and the environment, we are willing to explore new strategies that reduce our environmental impact, but we must maintain our bottom line profits. Ultimately, both high profitability and a high green score will lead to our company's success."

3 Changing the game design

Fundamental changes were made to the board game design, resulting in completely restructured game play, scoring and strategy. With rapid computation available on the computer version of the game, Shortfall was expanded to include ten rounds. This allowed for more flexibility in design, because players would be able to consider both long term and short term goals while evaluating environmental engineering changes [4-5].

The team structure was redefined to eliminate competition within the supply chain; instead the focus changed to a supply chain vs. supply chain competition, i.e., each student team consists of six players, who represented three companies in a supply chain (materials, parts, and cars (the original equipment manufacturer or OEM)). Although this structure does not entirely represent the reality of business (in which individual tiers of supply chains often directly compete against one another), it allowed development of a prototype to test the game in the new platform, while addressing a major complaint of the students – that the cooperative and competitive elements of the first version of the game were in direct conflict with one another.

To further clarify the competitive-versus-cooperative elements, scoring was modified to include five categories. A “green score” was introduced to provide an environmental goal along with the financial goal (in the board game, decisions with less environmental benefit resulted only in financial penalties). With several categories for scoring, teams are compelled to focus on these sometimes-competing goals for team success. For the current version trial, a supply chain team is declared the winner if they have outmaneuvered the other supply chain teams in three or more categories. Scores are tracked in the following categories: 1) greatest profit, 2) highest green score, 3) most waste removed, 4) lowest waste removal budget and 5) most cars sold.

However, a more sophisticated composite scoring system is planned in a future version to provide players with quantitative feedback about how they valued each aspect of the game. Students will be able to try different strategies to increase their composite score in subsequent games. At the game’s conclusion, the computer will report how different players might have approached the set of challenges – i.e., a player focused on environmental friendliness would have most likely selected one set of choices, while a player determined to win based on financial success would have selected a different set of choices. The student players will, we hope, compare their own scores to those of the computer-simulated players, and develop alternative strategies based upon these computer-simulated outcomes.

4. Rebalancing the game

Students identified key problems with the balance of the board game. These problems included the balance within the supply chain and in the current event cards. Therefore it was important to make the game as balanced as possible so that luck would not detract from the educational aspects of the game by creating a sense of unfairness.

To combat the issue of balance within the supply chain, the game was restructured to have each team play and compete as an independent supply chain rather than competing as independent materials, parts and cars companies. In future versions, this oversimplification will be addressed, but as a starting point, this change eliminated the problems identified for the parts supplier as being pinned between one auto manufacturer and one materials supplier [4-5].

Regarding the four player roles within a team representing a company team for the board game, students felt that the CEO had too much power, and that certain roles were not as fun as others. To change this outlook, each company team was reduced to two players. The CEO and Research and Development roles were combined into a single role (R&D), and the Waste Manager and Production Manager combined to form the second player's role (Production). These roles correspond to the decisions that each player is responsible for during each turn. The role of the R&D player is to make Innovation upgrades using the technology tree discussed later. The role of the Production player is to make the economic decisions about buying and selling. Both roles play key parts in increasing the company team score in all five categories and contribute to the supply chain team score.

The current event card system used in the board game was a valuable way to add realism to the game. Use of actual events that students might have heard about on the news – or even during a cooperative education experience – provides another level of connection. However, the students felt that some of these cards caused harsh effects only to certain teams, making the luck of the draw as important as any strategic play. The change to the orientation of the supply chain is likely to help assuage this issue, along with requiring that the same current event be applied globally to any competing supply chains. Examples of some of the current events imposed during game play are listed in Table 1.

Table 1: Randomly Occurring Current Events for Each Round

Current Event	Effect	Affected
Increased Cost of Financing	Market is reduced by 3 for the next round	All
Waste Storage Unit Leakage	Must remove all waste in facility and pay $200	All
Increased Gas Prices	All costs increased by $15 for next round	All
ISO Certification Required	Pay $1000 to get certified	All
Recycling Incentives	All "sell" prices increased by $50; Play a green innovation next round	All
Green Community Demands	If supplier has no green score innovations, pay $1500	All
Public Rewards Green	If green score is above 25, receive $500	All
Rail Strike	Materials supplier cannot buy raw materials next round	Materials
Aluminum Shortage	Materials supplier sells all inventory (no market premium next round)	Materials
Steel Price Hike	Materials "buy" price increased by $100; "sell" price increased by $50	Materials
Patent Royalties	Cars and Parts pay Material Supplier $75*round number	Materials
Machinist Strike	Parts cannot produce any product next round	Parts
European RoHS Legislation	Redesign to avoid hazardous materials; costs increase	Parts
Tier Emission Regulation	Parts pays $300 but cost to buy reduced by $35 and sell price up by $45	Parts
Optimized Glazing Systems	For each car sold next round, gain 2 in green score	Cars
UAW Contract Dispute	Cost to produce increased by $50 next round	Cars

5. Creating the technology innovation trees

The major educational component in the game, with respect to engineering and the environment, is the technology innovation tree. This tree allows students to appreciate how technology impacts the environment and what technologies are currently in use in the industry. The feedback from students who played the board game was that it was too easy to choose the technology upgrade based on economic factors alone. Also, there were too few choices of technological innovation and no full tree layout available for effective planning. For the computer-based version of the game, a technology tree was developed with the ability to view all of the options and paths to mastery before selections were made [4-5]. With a new game length of ten rounds, there were numerous possibilities for expanding the innovation tree, with innovations implemented throughout the supply chain in three areas of specialization: production, storage and waste.

A graphical interface was added to visually represent all options and to allow players to strategize and plan ahead. Figure 2 shows an overview with the materials supplier as the example, with the three inverted technological innovation trees (production, storage and waste) detailed in Tables 3, 4 and 5, respectively. For each supplier and OEM in the supply chain, a technology is selected from one of the three areas of specialization – from the first level of the tree (first rows in Tables 2-6 in the first round). To get to the second level of a tech tree (second row in Tables 2-6) in the next round, each supplier and OEM needs to have already invested in a second level one innovation in that same tree. To get to the third level, each supplier and OEM needs to have invested in one second level innovation in the same tree. To reach the technology mastery level for any area of innovation – at the bottom of the tree (fourth and last rows in Tables) – each supplier and OEM must have invested in a third level innovation in the same tree. To attain the ultimate mastery level, two other investments must also be made, both from level one in the other two of the three areas of specialization for innovation.

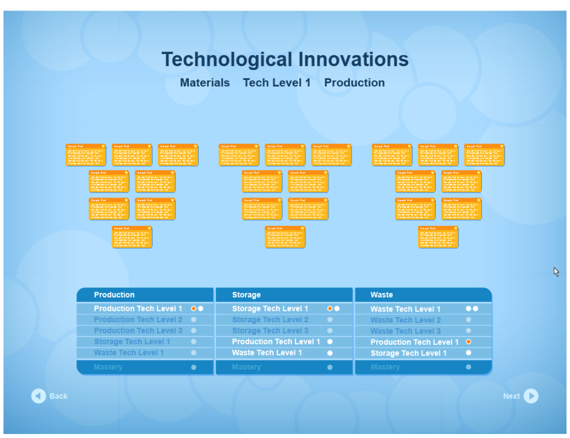

Figure 2 – Overview of innovations for materials supplier in production, storage and waste

After six turns and strategic planning for the right combination of upgrades, any team can reach a "Technology Mastery" in any given specialization. Achievement of "mastery levels" provides significant bonuses that relate to the specialization category. Due to the limited number of rounds, it would be impossible for any team to get more than one Technology Mastery during the ten rounds of play. This feature will increase replayability, encouraging students to try a different technology innovation path when playing the game subsequent times.

Another change made to game play involved the innovation tech trees for the part suppliers. The students that played on the parts team in the board game often felt that they had no control over the outcome of the game, because they relied directly on the materials and cars teams for all decision making. When the technology tree was redesigned, the Technology Masteries for parts suppliers all received an added bonus. This bonus not only increases the part supplier's abilities, but also impacts other tiers of the supply chain. By communicating within the supply chain, it is possible to reach a maximum upgrade to one technological specialization. Essentially, parts suppliers can strategize to give bonuses to the materials and cars company teammates, if they all choose to improve the same technological specialization.

The production innovation technology trees for Materials (Table 2), for Parts (Table 3) and for Cars (Table 4) impact the cost and waste associated with manufacturing materials, parts or final products. The left side of the tree has technologies that generally relate to cost reductions, while technologies on the right side have more impact on the environment. The tradeoffs for investing in each technology and for effects on green score are included in the game as mouse rollovers.

Table 2: Materials Suppliers Production Innovation Tree

Emission Control Coking operations for steel production require major investments and upgrades for emission control to meet Clean Air Act requirements.	**BOF Dust Recycling** Recovery of toxic metal dusts from steelmaking processes avoids placement of high zinc content dust in landfills and reduces needs for compliance with RCRA (Resource, Conservation and Recovery Act). Zinc can be reused and avoids pollution by heavy metals.	**Energy Reduction** Investment in heat recovery and recirculation equipment is used to capture to save energy.
PFC Emissions Research to identify cost-effective, techniques to reduce PFC (perfluorocarbon) emissions in electrolytic cells for aluminum production will avoid RCRA compliance requirements.	**Waste Water Treatment** Waste water treatment facility built on-site to remove additional toxic metals, reducing compliance requirements for RCRA.	
Strip Casting Strip casting technology for thin slabs allows faster production of sheet for autobodies.	**Glass Replacement** Alternative materials for glazing systems can reduce vehicle weight using thinner transparent panels. New materials can reduce the heat transmitted, and maintain acoustics at minimal price increase.	
	Electrolytic Cell Technology For electrolytic processing of aluminum, 20% reduction of energy consumption achieved.	

Table 3: Parts Suppliers Production Innovation Tree

<table>
<tr><td colspan="2">Advanced Machining Package
Automated machining, including robot welder CNCs used as boring tools, results in more flexible manufacturing, less lead time and greater variety of product.</td><td colspan="2">Powder Metallurgy
Powder Metallurgy parts can be made without machining and with any alloy design; they are widely used for manufacturing large volumes of complex parts used in automobile engines.</td><td colspan="2">Aluminum Engines
Use of aluminum engines reduces vehicle weight, and improves fuel economy to meet CAFE standards of the Clean Air Act.</td></tr>
<tr><td colspan="3">Advanced Lubrication Package
Use of new cutting fluids increases tool life, improves machinability, and facilitates automated high-speed machining and contributes to high productivity, thus reducing machining costs. Compliance requirements reduced for RCRA.</td><td colspan="3">Lead free seams
Lead free solder and seam fillers reduce worker exposure to lead-laced dust when sanding. Compliance requirements reduced for RCRA.</td></tr>
<tr><td colspan="3">Scrap Recovery Systems
Systems for collecting, separating and cleaning chips and metal scrap result in cost savings.</td><td colspan="3">Waste Water Filtration
Filtration of manufacturing waste water allows firms to eliminate settling ponds.</td></tr>
<tr><td></td><td colspan="4">Improved Brake Pad Materials
Brake pads made of material low in harmful substances reduce emissions of dust from pad grinding.</td><td></td></tr>
</table>

Table 4: Car OEMs Production Innovation Tree

<table>
<tr><td colspan="2">Advanced Machining Package
Automated machining, including robot welder CNCs used as boring tools, results in more flexible manufacturing, less lead time and greater variety of product.</td><td colspan="2">Tailor Welded Blanks
The production of TWBs involves welding multiple “blanked” metal body sheets into a single flat sheet, reducing the parts that must be separately stamped and assembled.</td><td colspan="2">Waterborne Paint Coatings
Although water-based paints still contain Volatile Organic Compounds (VOCs), aqueous paints reduce environmentally harmful emissions over solvent based paints, to meet Clean Air Act requirements, but increased painting costs result.</td></tr>
<tr><td colspan="3">Advanced Lubrication Package
Use of new cutting fluids increases tool life, improves machinability, and facilitates automated high-speed machining and contributes to high productivity, thus reducing machining costs. Compliance requirements reduced for RCRA.</td><td colspan="3">Powder-Based Paint Coating
Powder-based primer paints substantially reduce emission of Volatile Organic Compounds (VOCs), and have higher transfer efficiency, reducing production costs.</td></tr>
<tr><td colspan="3">Reduced Weight Vehicles
Substituting plastic and sheet metal parts for solid machined parts reduces vehicle weight and improves fuel economy.</td><td colspan="3">Improved Emission Controls
Improved emission control systems reduce pollutants in exhaust gas, exceeding Clean Air Act requirements.</td></tr>
<tr><td></td><td colspan="4">Improved Paint Spray Technology
Spray booth technology advances in filtration systems reduce paint spray emissions.</td><td></td></tr>
</table>

The storage innovation tree allows innovations that can reduce costs and increase capacities for storing production materials, parts, finished product or waste (Table 5).

Table 5: Storage Innovation Tree for All Stakeholders

KANBAN KANBAN systems avoid overproduction and minimize waste by closely monitoring material flows in the production/ assembly line. The result is little storage in the production area.	**AGV (Automated Guided Vehicles)** Automated Guided Vehicles move along predetermined paths and reduce the need for human workers, reducing the cost of storage and transport.	**Just In Time** With this type of assembly facility, very little inventory is maintained, as supplies are received only as needed. However, this makes companies more vulnerable during supplier work stoppages.
Cross Docking Full truckloads transported to centrally located warehouses, where the loads are cross docked to smaller vehicles. This saves fuel and reduces indoor pollution.	**Underground Warehouse Facility** Expand warehouse space by building underneath existing space. Use AGVs to manage remote inventory.	
Spill Containment Basins For warehouses that hold pollutants or chemicals, concrete basins underneath prevent spills from reaching the soil, reducing cleanup costs.	**Reusable pallets** Pallets that are returned for reuse save money and materials.	
	Explosion Blast Walls Wall constructed to blow out into areas where there is little risk of damage or human injury if an explosion takes place. Appropriate when solvents or explosives are stored.	

Disposing of waste safely and legally is a very expensive process. Innovations in waste management will reduce the cost of disposing waste and can increase the rate at which waste can be removed for that cost (Table 6).

Table 6: Waste Innovation Tree for All Stakeholders

Plastics Recycling Reuse of plastic containers and bins used in shipping leads to reduced packaging costs.	**Sorted Aluminum Recycling** Equipment for sorting various aluminum alloys in production scrap increases value of each recycled alloy stream.	**Scrap Segregation** High-speed sorting of metal and polymer scrap reduces handling costs and increases value of secondary materials.
Froth Flotation Plastics Recycling As more plastic is used in automobiles, recovery techniques developed to separate mixed polymer stream. No need for sorting waste stream.	**Corrugated Package Compacter** Installation of strategically located corrugated cardboard carton compactors reduces the scrap hauling cost and prepares the material for sale.	
Reuse of Rubber Scrap Recycled virgin rubber scrap from tires is used in other automotive parts, reducing materials costs.	**Reduced use of solvents** Strategically placed degreasing stations reduce solvent evaporation into air.	
	Regrind of Scrap Polymer Composite Grinding of home scrap polymer composite is used for front end fascia of vehicle.	

6. Testing the digital game play

The ideas for the prototype computer-based game were presented in an unfinished form to both undergraduate and graduate engineering students an engineering course entitled "Environmental Issues in Manufacturing and Product Use. Fifteen students (nine graduate students and six undergraduate students) had enrolled for the Spring 2007 term. A class period was spent discussing the board game (which several students had played in a different class) and then a demo of the computer-based version was presented, although students were not able to actually play the game. Feedback from the students in this class was used to increase usability and to create a more informative introduction for new players.

A full play test was scheduled in June 2007 with approximately seventy students in the mechanical and industrial engineering senior capstone design course. Each company in the supply chain (representing materials, parts or cars) was played by two players, making the total number of student players as 6 per supply chain team. The game in its current form is flexible enough to support any number of teams of six, as long as a laptop is available for each one; however, the current scoring algorithm, requiring a win in 3 of the 5 score categories becomes harder as more teams are added, potentially resulting in no team "winning" the game.

For the in-class play test, each of the 17 supply chain teams was provided with a laptop. Prior to game play, all students answered a short survey on the knowledge base prior to playing the game, as was done previously [3]. During each round, the students passed the laptop around to their supply chain team members, allowing each team of two in the supply chain team to make their decisions. At the end of each round, the scores were tabulated from the laptops to determine how the game proceeded. At the end ten rounds, the team with the highest combination of scores was declared the winner. After game play, students answered the same short survey in an effort to measure learning. In addition, students provided written feedback to help with subsequent game revisions. The game was played in the capstone class near the end of the term – just before their final presentations, and many students left survey questions blank on the follow-up survey, leading to indeterminate assessment of learning. But many students provided comments for improvements to the game play, and these comments are being used for continued revisions.

7. Conclusions

Solutions to environmental problems associated with human endeavor are generally interconnected with many factors, including technological and economic constraints. With increasing costs of pollution remediation, environmentally benign manufacturing initiatives are becoming more common in industry. Anticipated environmental regulations and liabilities also act as drivers for change. To create a culture for change in industry, engineering students must begin to understand how to assess the tradeoffs among economic, technical and environmental factors if they are to become socially as well as fiscally responsible designers, manufacturers and leaders.

As the development of Shortfall continues, real data about current and past events and innovations in materials, tools, and processes will be "simulated" within the game through scenario generation, so that students will see the projected effects over time [6]. The game projections will be based on actual engineering data, but simplified to fit within the parameters of the game. A "plugin" architecture will also allow for the introduction of new data or the creation of additional simulation modules as new current events and innovations become important to the curriculum this game supports; new modules can even be created by engineering instructors (or as homework assignments by students) without a heavy programming background. The Shortfall game engine will present the results of player actions in the context of real-world scenarios that are drawn from a database. The database of scenarios will be created by graduate students and faculty, using discrete event based modeling that is based on supply chain operations. These scenarios will describe conditions or situations that reflect real world environmental and production issues faced by engineers, designers and managers. The scenarios will be presented to the players at appropriate times and will be dependent upon the decisions that are being made within the game structure.

Players will have a personal computerized “advisor” available to provide hints on the possible outcomes of their actions with “just in time” help with game concepts and strategies. The advisor’s role, however, is limited to assessing the short-term and long-term effects of whatever single action the player proposes. The combinatory effect of all players’ actions and decisions remain for the team to strategize and learn.

While Shortfall has only begun its transformation to an online multi-user learning simulation, the foundation has been laid. Assessment and follow-up on student comments after playing the prototype board game suggested methods to best leverage technology for development of the game. Shortfall was designed to raise environmental awareness of engineering students through game play, and we anticipate that testing and development of multiple iterations of screen-based digital versions will allow us to ultimately design a game that allows better understanding of engineering and social issues on a complex relational systems level.

Engineers will play a critical role in addressing the challenges of sustainability. Environmental issues are not “cut and dry” problems with simple answers; rather, they are interconnected with technological and economic constraints. Enhancing economic and environmental literacy among engineering students provides real ethical dilemmas for debate, and will contribute to defining a new pedagogical model for educating future engineers.

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References

1. J. Corriere, “Short Fall: An Educational Game on Environmental Issues in Supply Chain Management”, M.S. thesis, Mechanical and Industrial Engineering, Northeastern University, Boston, MA 2003.
2. J. A. Isaacs, T. P. Cullinane, D.M. Qualters, A. McDonald, J. Laird. *“Games as Learning Tools to Promote Environmentally Benign Systems”*, LCE2006, 13th CIRP International Conference on Life Cycle Engineering, May 31 – June 2, 2006, Leuven, Belgium. http://www.mech.kuleuven.be/lce2006/139.pdf
3. D. M. Qualters, J.A. Isaacs, T. P. Cullinane, A. McDonald, and J. Laird, *“Assessment of Shortfall: A Board Game on Environmental Decisionmaking”*, Proceedings of ASEE 2006 Annual Conference and Exposition, June 18 - 21, 2006, Chicago IL, American Society for Engineering Education (ASEE), Washington, DC, CD-ROM. http://www.asee.org/acPapers/code/getPaper.cfm?paperID=10324/

4. S. Sivak, M. Sivak, J.A. Isaacs, J. Laird, *"Evolution of Multiplayer Educational Simulations: Board Games to Broadband"*, GLS: Games, Learning & Society Conference 3.0, July 12-13, 2007, Madison, WI.

5. S. Sivak, M. Sivak, J.A. Isaacs, J. Laird, A. McDonald, *"Managing the Tradeoffs in the Digital Transformation of an Educational Board Game to a Computer Based Simulation"*, SIGGRAPH 2007, The 34th International Conference and Exhibition on Computer Graphics and Interactive Technologies, August 5 9, 2007, San Diego, CA.

6. A. Torabkhani, J. A. Isaacs, J. C. Benneyan, *"Embedded Simulation Models in Educational Games on Environmental Issues for Engineering Students"*, 2007. Proceedings of the 2007 IEEE International Symposium on Electronics and the Environment, 7-10 May 2007, Orlando, FL.