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A Game Approach to Teach Environmentally Benign Manufacturing in the Supply Chain

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Keywords

Engineering education, Game theory, Millennial student, Environment

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Abstract

Multidisciplinary models of education are needed to prepare students for their role in a global work environment. Combined with this need is the reality of the new Millennial Generation entering the educational system with a different approach to learning. This paper introduces an interactive, educational engineering game designed to appeal to the Millennial Generation's learning preferences. *Shortfall* is a prototype board game with a team approach and a trial and error methodology to introduce students to environmentally benign manufacturing in the supply chain using the automobile industry as a model. After playing the game, quantitative analysis showed that on average, students gained new knowledge and a changed perception of their confidence in their answers. Qualitative analysis of data demonstrated that students felt the game also helped them with the teamwork/communication aspects of supply chain. Future plans involve converting the game to a computer format to streamline its effectiveness for multi-institutional participation.

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Introduction

There are few multi-disciplinary educational programs that merge issues related to business, environment, and engineering. Traditional education models instruct students in their field of choice with little introduction to the multidisciplinary interactions that take place in industry. As a consequence, graduates new to the entry-level work force, often lack the knowledge and skills to understand their role within the company and their company's role in the global marketplace.

The use of interactive educational games can provide students with solid learning experiences and lessen this gap. Gaming and simulation strategies have long been used in the military sphere for training and assessment, because these techniques are proven to help individuals and teams learn strategic decision-making and planning in complex systems with multiple variables. Business and management games became prevalent starting in the 1950s and 1960s as a method of simulating strategic and operational decision-making over time. In the 1970s, fields such as urban planning and social sciences adopted gaming and simulation in research and teaching (Mayer & Veeneman, 2003). One of the primary reasons cited in the rise of the gaming simulation as a research and learning tool is the ability of participants to interact and safely and quickly receive dynamic feedback from representational models or computer systems that mimic the dynamics of reality. These interactions can occur individually or in groups, allowing participants to compete, experiment, and intervene, actively learning about infrastructure complexity and consequences of decision-making (Mayer & Veeneman, 2003), thus allowing their knowledge and skills to be developed as active and transferable (Kriz, 2003). Gaming simulation incorporates key elements of successful learning strategies such as "trial and error and the benefit of immediate feedback about the consequences of participants' decisions." (Kriz, 2003)

In yet another, more recent work (Wideman et al, 2007), the authors point out that:

"Properly designed educational games, it is argued, can function as practice fields (Senge, 1994), which engage learners in many of the authentic tasks of a real-world community of practice and require the application of the same problem-solving and critical-thinking skills. These authentic practices are fundamental to the development of domain expertise, which is evidenced in an advanced capacity to recognize patterns and work with deeper organizing principles and core concepts (Bransford et al., 2000). The limited research to date on the social context of game play and learning suggests that games do foster goal-directed social interaction that may facilitate collaborative learning (Kirriemuir & McFarlane, 2003).

This last citation clearly indicates a need for "successful demonstration projects that are rigorously evaluated" to determine the value of gaming in education. We believe that there is much to be learned about the effectiveness of educational games and that the platform we proposed would allow appropriate study of student learning in a field (engineering) where educational games are not as widely utilized.

Shortfall, the board game, was created as a prototype educational tool that attempts to address communication barriers and to highlight environmental issues in the automobile supply chain. *Shortfall* uses a simple, manual-method structure as an interactive, role-

playing board game to promote interactive interdisciplinary learning. The game facilitates the education of players about the automobile supply chain, from research and design to production and disposal, legislation, and environmental awareness. It also incorporates costs associated with decisions, while fostering development of communication and interpersonal skills, and appreciation of the benefit of interdisciplinary teamwork. Awareness of the environmental repercussions of operating a manufacturing facility and materials selection decisions are essential for future generations of engineers and business practitioners.

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. Anticipation of environmental regulations and concurrent liabilities also act as drivers for change. However, creating a culture for change in industry involves more than just changing perceptions of current practitioners. To have a self-sustaining culture, engineering students must also be made aware of the issues and challenges of environmental issues as a part of their education. 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.

Educational research is beginning to shift the focus from the classroom to emphasize learning through active engagement with discipline subject matter. In today's classroom, exploration of the tradeoffs in the triple bottom line (i.e., profits, environmental sustainability, and social responsibility) is most often limited to lectures and descriptions of case studies (Elkington, 1998). Given the technological context in which children are raised in the United States, the standard lecture, homework, and even application assignments may not be the best method for teaching and communicating new ideas. The current pedagogical challenge involves engaging students who come from the Millennial Generation. As will be described later, these students bring a different set of challenges to the classroom including varied learning styles and technological expectations. The decision to use a game methodology reflected, in part, a response to the current educational concerns around the Millennial Generation and their impact on higher education (Howe & Strauss, 2000, 2003).

The game, *Shortfall*, was designed as a prototype board game to teach students about environmentally benign systems design through simulation of a supply chain in the automotive industry. This game is viewed as a complement, or possibly an alternative, to the traditional lecture/case format used in most colleges and universities. The researcher's major objective for the *Shortfall* board game was to test gaming as a potential tool for student learning and to receive feedback in order to devise a computerized version. It is our belief that this game encourages the exploration and adoption of new, more exploratory teaching techniques and increases active engagement with the material on the part of the learner. The prospect that a learning tool of this nature will encourage entrepreneurial and interdisciplinary thinking presents significant opportunities for transformation in higher education. Although the intent has always been to ultimately create a networked computer game, it is a common game design practice to first develop a "paper prototype". In the case of *Shortfall*, because of the highly collaborative nature of game play, it was easier to test the idea by observing a group of students "playing out loud" with physical boards, cards, and pieces.

Background

The Millennial Student

Every generation feels that the next generation differs in some significant respect. Born in the 1980s, Millennials were reared during the era of the wanted and watched child. This generation is often perceived as dependent on the adults who protected, scheduled and structured their lives. Millennials, however, are also a pressured high achieving generation that accepts authority and follows rules (Phalen, 2004).

Howe and Strauss (2000, 2003) suggest that each generation rebels by solving a problem faced by the previous generation, correcting the mistakes of adults and leaders. Therefore it is not surprising that today's student is inherently different from its predecessors. Technology has been the greatest influence and has changed the definition of literacy for this generation (Brown, 2000; Sharp, 2005; Petroski, 2005). Significant disparities in millennial student learning styles and those of their instructors have also been documented (Howe & Strauss, 2000; Golden, 2003; Sandfort & Haworth, 2003). The implication for education is the realization that Millennials are being taught by a generation of faculty who have a very different approach to learning.

Another educational challenge is preparing students for conditions in the real world of practice. While Millennials are computer savvy and technologically advanced, they often lack important social competencies because of the increased amount of time spent in isolation at a computer as opposed to interacting with people (Phalen, 2004; Ball, 2003). Nascent research on the Millennials is beginning to demonstrate that this generation of students has experienced group learning settings and group evaluation since elementary school. The irony here is that students are not trained in the soft skills needed to work in groups, nor do teachers often explicitly teach the social skills of group work; therefore, much of group interaction is frustrating for both students and faculty. There is an extensive body of education literature addressing skills and techniques that instructors need to master when using groups in learning settings, but until this literature is used to develop 1) team skills in students and 2) the teaching framework for group work for faculty, this seeming contradiction will continue to exist.

This is part of why the social-cooperative aspect of *Shortfall* is so important. As stated, Millennials are used to being organized in to teams, but this organization is more akin to the assembly of parts in a machine: each millennial student learns his or her role and performs it as part of the contribution to the whole, but they only see the value of own contribution and the end product; they do not appreciate the many systemic layers between themselves and a final collaborative product. This is partly because Millennials prefer to be "self-teaching", and thus do not appreciate the diversity of skills that others around them may be able to offer. The "co-opetition" model of *Shortfall* (companies competing to survive in a crowded marketplace for increased profit) while also trying to cooperate for the greater good (of reduced environmental impact for all) causes the Millennials to have to balance their abilities to perform an isolated task well with the need to help others perform their tasks.

Millennials appear to have unrealistically high expectations of how the workplace should be structured and what their role is in an organization (Zemke, 2001). And of course, to this generation, computers are not 'technology', but rather a part of life (Golden, 2003). Wankat and Oreovicz (2005) indicate that members of this generation are referred to as 'gamers' because they play video games for more than 20 hours/week and their favored learning

style is inductive without formal instruction. The differences in learning styles, technology usage and workplace expectations of the millennial student will have a significant impact on effective methods of teaching and learning in higher education.

Pedagogical Issues

Learning Styles

Learning styles have come to categorize the ways students receive, process, and express information. Although many different instruments and measurements exist, there is some consistency along the dimensions of learning measured. Golden (2003) has pointed out two significant differences in the learning style of millennial students. First, Millennials approach problem solving differently from their teachers. Previous generations utilized a logic-based methodological framework, while millennial students favor a trial-and-error approach whereby each time they fail, they are taking a step towards learning how to succeed. The second factor points to the heart of teaching. Previous generations came to higher education seeking information and facts, often through lectures. Today's generation has unlimited access to information that they view as constantly in flux, so these students are more interested in learning through action and results. Furthermore, research on engineering students suggests that they learn best in an environment that is active, sensing, visual and sequential (Wofle, 1997; McDevitt, 1997; Rosati, 1999). *Shortfall*, the board game, was designed to appeal to this learning style. Through the use of trial and error and active engagement with "real world" problems, our hope was that the game would engage students, generate knowledge, and help move learners from a novice state to a more competent professional state in an appealing way.

Solitary versus Group Decision Making

While previous generations have valued solitary contributions, today's students are communal in their approach. Learning is moving out of the individual sphere into a more collaborative environment. This is a generation brought up with cooperative and collaborative learning models from elementary school. Research results support collaborative models, and are showing that these approaches enhance critical thinking and development of team skills (Johnson, Johnson & Smith, 1991; Bruffee, 1995). Zemke (2001) has characterized these students as having a "leave no one behind" attitude. The theories of situated learning and communities of practice (Lave & Wenger, 1991; Wenger, 1999) have documented the increased learning that occurs when learners with real problems come together to work on solutions to real problems. Communities of practice have also evolved through technology into virtual worlds of practice. Thus participants can be co-located around the world in a solitary environment, yet interact and feel part of a communal team. In other words, through interaction with others, learners are able to articulate the tacit knowledge that they have acquired and examine the validity of their assumptions to increase the learning for everyone.

Redefining the Concept of Teaching/Learning

Another factor directly influencing the millennial student arrival in higher education is the very assumption about what constitutes teaching and learning (Howard, 2000). Instructional delivery is no longer bounded by physical location. The introduction of the Internet into the teaching/learning dynamic has broadened the classroom walls and allows delivery of information in ways that honor multiple learning styles. The increased interest in experiential learning such as service learning, internships, cooperative education and study abroad create different learning environments for today's students. The technological and

global opportunities available to today's student are challenging the classroom environment to be more authentic. There is an opportunity to provide students with learning environments much more attuned to their individual styles (Brown, 2000).

Learning through Simulation and Gaming

To address the social, educational and technological issues of today's world, new approaches to classroom learning are anticipated. While discipline-based knowledge is critical, so too will be process learning. Education will need to involve a balance between the content curriculum and the hidden curriculum of team building, problem-solving, and critical and creative thinking. Many engineering subjects have been characterized as theoretical, thereby lending themselves to didactic lecture-based instruction followed by rigorous and sometimes tiring problem solving assignments and activities. Although there is no perfect alternative to such an approach, traditional lecture-based learning, standardized testing, and separated disciplines will need to change in Science and Engineering education if students are going to be taught a full range of required topics and creative thinking skills. Research is continuing to confirm this by showing that experienced-based learning offers new ways of facilitating student learning (Wronecki, 2004). One method for fostering both content and process knowledge and skills is through the use of interactive simulations and games as a legitimate form of learning (Mayer & Veenaman, 2002; Poggenpohl, 2003).

The Society for the Advancement of Games and Simulations in Education and Training (SAGSET) is a voluntary professional society that formed in 1970 to improve the effectiveness and quality of learning through the use of interactive methodologies, role-playing, simulations, and games (SAGSET, 2003). According to SAGSET, simulation and gaming are strong teaching tools because the participants are required to be directly involved in the decision making process and thus, these tools allow for learning of interactive decision making. Such games and simulations create memorable experiences that motivate students to continue to learn. In looking at the theoretical foundations of games, some authors noted that the game playing took students through three important phases to facilitate learning: 1) experience, 2) reflection and 3) learning (Brougere, 1999).

Simulations are designed to meet many of the challenges mentioned by mimicking real world situations and forces, simplifying reality through a dynamic, abstract model, often exaggerating real world experiences to improve understanding or compact time. The use of simulation as a learning tool allows a student to ask "what if the system were different" and to actually explore how the system might react under varying conditions.

Environmental Issues in the Automobile Supply Chain

The Automobile Supply Chain

The automotive supply chain is one of the largest in the world. The effect of the Original Equipment Manufacturer (OEMs) on its supply chain and the economy is powerful; success and longevity of the industry are key to the future economic growth of the country (UNEP, 2002). The effectiveness of the supply chain is critical to the success of all the businesses involved and thus was chosen as the subject matter for the game.

The supply chain is defined in *Shortfall* as the upstream flow of products, services, finances, and information from a source to a higher point in the value chain. The supply chain in the automotive industry involves a series of suppliers that contribute to the finished product. Raw materials are converted to useful materials that are sold to various suppliers to create

numerous parts that are assembled to fabricate the finished goods. Effectiveness of the flow of materials in and out (both desired materials and waste streams) of a company becomes key to the success of the business. The structure of the value chain includes the OEM, 1st tier suppliers, 2nd tier suppliers, etc. The current structure often allows the OEM to accrue the largest profit margins and often to defer responsibility for the environmental effects of its product, though this is changing.

Supply chain management is defined as the planning, implementation and control of the operations of the supply chain from raw materials to the product as delivered to the customer. It can include improvement of the supply chain as a whole by analyzing the long term performance of each individual company involved in the chain (Mentzer, 2001). Supply chain management also includes decisions on materials handling, storage and inventory. Proper supervision influences the performance of each individual company function: research and development, engineering, sales, and promotion (Forrester, 1958).

When considering the triple bottom line, the management of the supply chain is likely to change as alternative objectives are addressed. Extended producer responsibility (EPR) regulations are prevailing in the European Union (EU), where EPR is defined as the extension of the responsibility of producers for the entire product life-cycle. Manufacturers (OEMs) are held financially responsible for the take-back, recycling, and disposal of end-of-life products. Hence the materials utilized to fabricate the product require accountability for responsible disposal, otherwise OEMs face legal ramifications. The EU Vehicles End-of-Life Directive (2000) requires OEMs to design vehicles and components without hazardous materials and to take responsibility for vehicles (and components) at end-of-life. Given a perceived threat of U.S. legislation to require EPR as well as a desire to sell in the international market, many OEMs are becoming more selective for their suppliers, inducing their suppliers to proactively embrace environmental standards to further improve their position within the supply chain. The auto industry will presumably continue to grow, despite recent downturns. Growth will continue to intensify the environmental ramifications and competition between U.S. and foreign manufacturers, further justifying the need for a well managed auto supply chain (EPA, 1995).

Shortfall: The Enhanced Board Game

Existing Games

The challenge of the new classroom, millennial student and environmental concerns led to the conceptualization of a strategic game to build on the strengths of the current generation and to capitalize on the newest theories of learning to help students understand the strategic tradeoffs in the triple bottom line. Games such Fish Banks LTD (UNH-Fish Banks, LTD, 2003), Stratagem (Meadows, 2001), The Beer Game (SDS, 2003), Georgia Basin QUEST (Utne, 2003) and SimCity (UTNE, 2003) indicate that the use of interactive games can provide solid learning experiences. Keys & Wolfe (1990) trace the history of business games used in the classroom to the 1950s, evolving from the intersection of war games and educational theory, including the 1955 Rand Corporation game *Monoplogs* that was designed to teach management and logistics of the U.S. Air Force supply chain. The entwined history of games and learning can be traced back even further to Chinese war game simulations as early as 3000 B.C. (Arneson, 2003). Other relevant games included, Waste: The Business Game (Arneson, 2003), Industrial Waste (2003), MARK (Funagain Games, 2007), Dog Eat Dog (Funagain Games, 2007). While this is a solid foundation, there are few multi-disciplinary educational programs, activities, or training programs that

merge issues related to engineering, business and environment. *Shortfall* was developed to provide this multi-disciplinary approach.

Game Design

There are four basic formats for games: simple manual exercises, card games, board games, and computer-based exercises. Common protocol in game design involves development of the gaming concept through first building a "paper prototype" to generate feedback for further development of a computerized game (Fullerton, 2008). Often these prototypes do not capture the full flavor of the final computer design; for *Shortfall*, we focused on making the game as much like the future networked game as possible. *Shortfall*, the board game, is the prototype developed to test our theories and beliefs about the Millennial Generation before proceeding with the far more expensive and expansive computer game. We felt that by studying our prototype we would be able to gain valuable student feedback, gain some understanding of meeting our learning objectives and have data with which to proceed.

The design of *Shortfall* utilized simple manual exercises, with role-play exercises that required a combination of role cards, briefing sheets, and/or booklets. Simple manual exercises can be organized using five distinct structures: linear, radial, cycle, interactive, and composite structures. *Shortfall* utilized a composite structure because its goals were complex, and several structures were used to accomplish the game objective. The game simulated a simplified supply chain for an automobile manufacturing operation with the goal of game play to minimize environmental impact while maximizing profit, and further, to foster better understanding and dialogue of these issues. *Shortfall* was originally developed as a board game as part of an M.S. thesis (Corriere, 2003) supported by the National Science Foundation, and was played several times with students in engineering classes and once with students in a business class. An early prototype of the board game was formally assessed, and both engineering and business students indicated that they enjoyed playing it, and moreover, that the game was informative.

A revised board game prototype of *Shortfall* was more extensively developed with increased attention to game play logistics, more fully developed scenarios and graphic organization. *Shortfall* was enhanced to help students meet learning objectives in the following areas:

- History of environmentally benign technologies within the past decades
- Environmental policies and legislation that influence manufacturing in the global economy
- Tradeoffs among economic and environmental policies that influence technology
- Current strategies used in industry to address environmental issues
- New technologies that address reductions in environmental burdens
- Social, economic and business issues associated with decision-making
- Effects of current global events on a sophisticated and complex supply chain

Within this framework, *Shortfall* became an educational, decision-making, multi-person role-playing game. The fundamentals of the game promote awareness of the interrelated relationships for the production of raw materials, parts and automobiles within the automobile supply chain. There are two components for strategy in this game: 1) decision tradeoffs among specific company personnel on a given team and 2) decisions to make the team's company competitive.

The revised board game prototype was piloted in the fall of 2005. By addressing issues in two dimensions of Ball's cyclical model (2003), the prototype utilizes new trends in cognitive learning to develop a new learning tool to begin to test the hypothesis that millennial student learning styles differ from their instructors. The goal of the revised prototype is to teach students that the decisions that are made in design and manufacturing can have a significant impact on the environment. It is also important to note that decisions with respect to the environment are not always "cut and dry". We wanted to impress upon the players that most decisions that involve the design of products, design of equipment to produce products or the disposal of manufacturing waste involve tradeoffs and weighted decision making. The game is envisioned as a way to promote cooperation, strategy building for the greater good and increased knowledge of duties beyond traditional roles.

In the board game, players each take on one of four roles in a company: the CEO, the Environmental Manager, the Research & Development Manager, or the Production Manager. Each four-player company assumes a role in a simplified automobile manufacturing supply chain: the OEM who produces the cars, the Tier 1 supplier who produces parts, and the Tier 2 supplier who produces the useable materials from raw materials that create parts as shown in Figure 1.

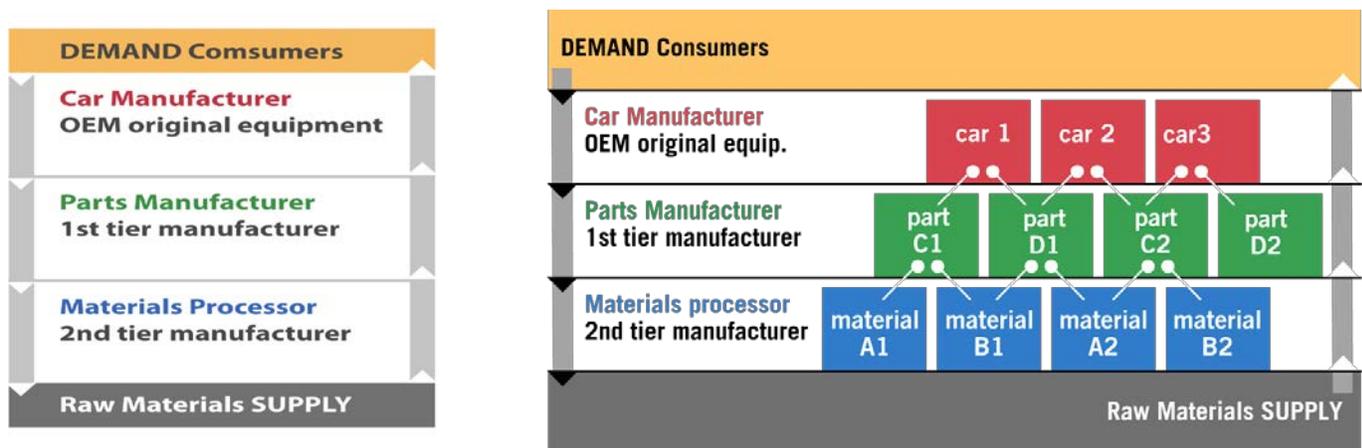


Figure 1: a) The simplified supply chain and b) the expanded simplified supply chain

The Rules

The game is played in a series of rounds, each of which represents a fiscal quarter. At the beginning of the game, each CEO in each company in the supply chain must allocate funds within the company to three managers using a game board shown in Figure 2. After allocation of funds, all managers must decide how money will be spent in their primary areas. The roles for the CEO and the managers are designated as:

CEO: The chief executive officer is primarily concerned with the welfare and total cash supply of the company. The CEO makes the ultimate decision on how to allot company resources to increase the company's total income.

Production Manager: The production manager is concerned with the production issues, and tries to persuade the CEO to dedicate resources to the manufacture of product.

Environmental Manager: The environmental manager is primarily concerned with meeting the environmental regulations, especially regarding waste disposal for the production processes, and tries to persuade the CEO to dedicate resources to waste disposal.

R&D Manager: The research and development manager is primarily concerned with the new technology development for the company, and tries to persuade the CEO to dedicate resources to R&D.

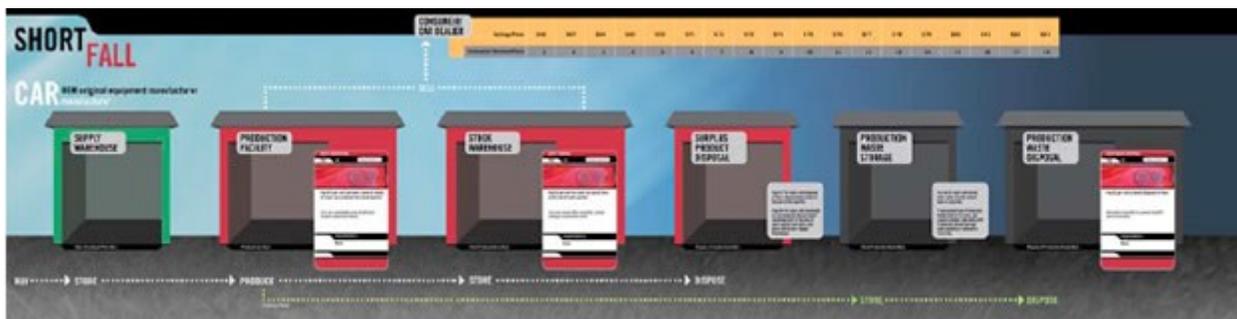


Figure 2: Sample Game Board for Car Team in *Shortfall*

Features to enhance understanding of the tradeoffs among the triple bottom line in the board game include using “Current Event” cards that hold positive or negative ramifications for each company in the supply chain. Events such as work stoppages, economic factors and natural disasters are included, as well as the influence of environmental regulations.

The challenge for Production Managers is that companies may only sell a product that is ready to ship. Therefore, teams must plan production at least one quarter in advance, hoping that their predictions about the other teams’ needs (and random market fluctuations) will be correct. The production of new product is limited by: each company’s production budget, the number of parts/materials that each company currently has available, and the amount of product and waste storage that the company currently has available.

After sales and production, the Environmental Managers must handle waste disposal, material recovery, and recycling. The company is assessed a fee for disposal, but may be recompensed for responsible disposal or recycling.

Finally, the R&D Managers spend any part of their budgets on factory improvements, which may reduce waste, lower production costs, or take steps towards future innovations through the use of “Innovation Cards”, which require financial investments to be exploited. These cards are strategically used for emission and cost reductions in production or storage through various technological innovations. Figure 3 illustrates several of the Innovation Cards designed for the *Shortfall* board game. Each team has cards that reflect their company’s technology needs.

At the end of the quarter, any unsold supplies, product or waste are assessed a storage fee, and a “Current Event” card is drawn. Again, these cards describe real-world situations

ranging from air pollution regulations to landfill seepage. There is an immediate penalty or reward to one or all teams; sometimes the card affects the play of the entire next quarter by imposing a fine for some action that could have a negative impact on the environment or some other issue related to waste disposal.

In the final 5th quarter of the game, players do not produce further products, but instead sell off remaining product and overstock supplies, and dispose of remaining waste. After all products are sold and waste disposed, the team with the most profit is declared winner of the game.

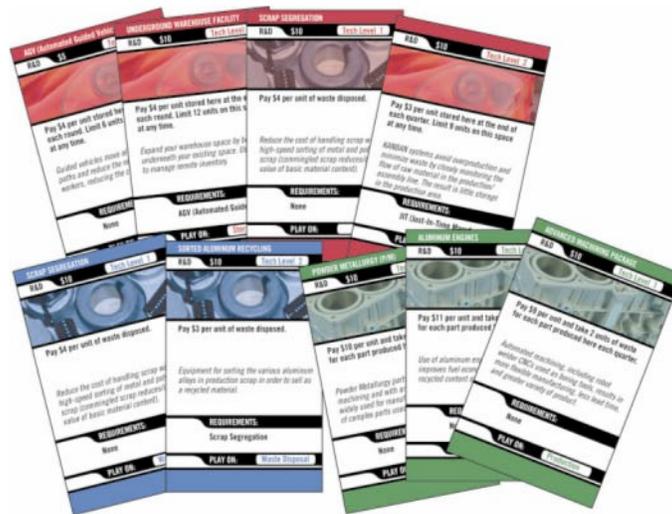


Figure 3: Sample Innovation Cards for *Shortfall*
Gathering Data about Game Play

As part of the game testing process, Industrial Engineering sophomores were solicited to play *Shortfall*. Twelve students volunteered to participate, some of whom are shown in Figure 4. Final participants included nine females and three males with self-reported GPAs ranging from 2.87 to 3.92. Because student participants were self-selected volunteers, we had to think carefully about the type and amount of data we could realistically expect to collect within a proposed 90 minute total playing time frame.

We began with a pre/post survey of knowledge, but did not utilize the traditional model. Prior to playing the game, students were administered a pre/test knowledge survey (Nuhfer, 2003). This type of survey was selected for its dual purpose: 1) it serves as a pre/post assessment measure of student knowledge and 2) it measures changes in pre/post self-assessment of student confidence in their knowledge base. Knowledge surveys have also been used successfully in other educational studies related to SMET disciplines (Nuhfer, E.B., 1996; Bowers, N., Brandon, M., & Hill, C., 2005; Wirth, K.R. & Perkins, D., 2005). Students were asked to answer ten questions listed in Table 1 on their knowledge of supply chain and environmental issues related to manufacturing. Students were also asked to rate their confidence in answering each question: "A" if they felt confident that they could currently answer the question sufficiently if this were a graded test (which was scored numerically as 3); "B" if they could currently answer 50% of the question or if they knew precisely where to get the information needed and return in 20 minutes or less to provide a

complete answer if this were a graded test (which was scored numerically as 2); and “C” if they were not confident that they could adequately answer the question for graded purposes at this time (which was scored numerically as 1).

After round two of the game, we administered a brief questionnaire asking students to identify what “new information” they had gained regarding supply chains and/or working in a team situation. At the end of the five rounds of an approximately 80 minute game, students were administered the identical knowledge survey to which they had initially responded.

Students were also asked at the end of the game to respond to a program survey identifying the strengths and weaknesses of *Shortfall* as a board game to provide information for the computerized version. Finally, one week after the playing the game, students were invited to return for a focus group exploring their experiences with the game and their perceived feelings about *Shortfall* as a learning tool. Nine of the twelve original students participated in the focus group.



Figure 4 a and b: Students During Game Play

Knowledge Survey

Analysis of the questions in the knowledge survey (Table 1) showed that on average, students gained new knowledge and a changed perception of their confidence in their answers as a result of playing the game. As indicated in Figure 5, the mean scores reflect a change in knowledge resulting from playing *Shortfall*, and seem to indicate a gain in knowledge on all questions with the exception of question 7. Increases in knowledge varied from a mean value of +0.08 ($\sigma = 0.79$) in question 10 to a mean value of +2.42 ($\sigma = 1.16$) in question 9. Question 7 resulted in an overall decrease in knowledge ($x = -0.42$, $\sigma = 0.51$). Analysis of the confidence data showed that in general, students felt more confident about their knowledge after playing *Shortfall*, as indicated in Figure 6. As students played the game for only 80 minutes, it was interesting to see gains in knowledge at the same time that they were learning to play the game.

Qualitative analysis of the student perceived learning after round two revealed a new understanding of the role of waste in manufacturing, cost factors in R&D and storage, the connections between supply chain tiers, and the role of unexpected factors in

manufacturing. One student put it best, "I did not know anything about supply chain and now I know about basic features of what happens after each step."

Students also came to a new appreciation of business structures and team work, an important characteristic of Millennials. The strongest perceived learning was in two areas: importance of communication and the role of working together. As a student stated, "everyone has to know what is going on or else you can't play as a team and make decisions", another student couched their response in terms of trust – "[you have to] give your input, but trust the person in charge of the area, they have studied their area more than you have and everyone has to do their job".

While we can not explain the knowledge gains in content and process solely in terms of learning styles, we feel that the trial and error methodology of the game and the competitive/cooperative model played a role.

Table 1: Questions for Knowledge Survey

- Q1 What are 3 positive features of just-in-time manufacturing?
- Q2 List 5 environmental issues associated with production systems in an automotive supply chain.
- Q3 Name 3 processes associated w/ the reclamation of waste material from manufacturing processes.
- Q4 Identify 2 government based standards that impact the manufacturing of an automobile.
- Q5 Identify 2 operations in the manufacturing life cycle that can be performed by automated equipment.
- Q6 In what areas do companies make trade-offs when striving to maximize profits?
- Q7 What types of materials are used in the production of engines?
- Q8 Identify 5 main characteristics of a successful supply chain.
- Q9 Name 5 events external to the main supply chain that can impact business practices.
- Q10 Name 2 materials that are necessary to produce an automobile but may not appear in the final product.

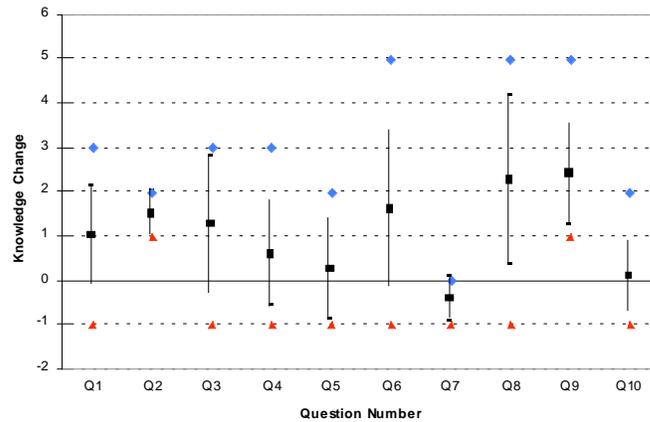


Figure 5: Mean knowledge change for each question in the knowledge survey, shown as square markers. Diamond markers indicate maximum individual gain in each question, while triangle markers indicate minimums. Standard deviations are indicated for each question. (N = 12)

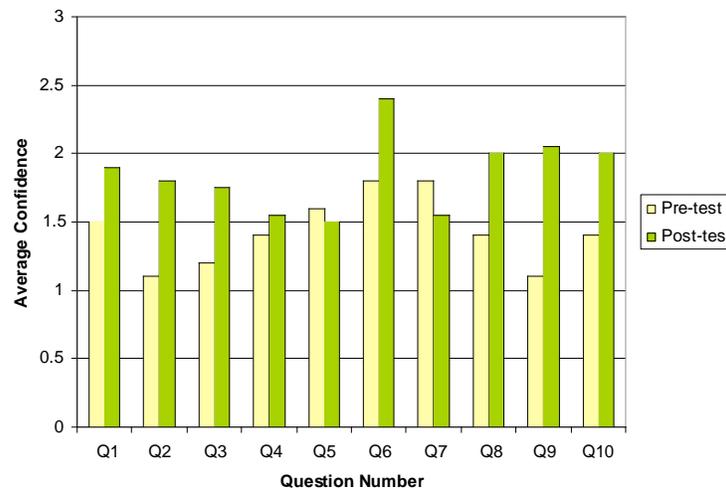


Figure 6: Average confidence of student knowledge before and after *Shortfall* game play

Program Survey

Feedback around perceptions of the game immediately following play produced useful and interesting information regarding the strengths and weaknesses of *Shortfall* and again focused on areas that research has identified as characteristic of this generation. Their overall suggestions for improvement fell into two distinct categories: clarity and realism.

A majority of suggestions centered on the clarity of the game, i.e., better instructions, an initial overview, more introductory explanations, and clearer step by step directions. Other suggestions included providing strategy planning advice and information on how choices affect the game. In the second category, students requested making the game more realistic. Suggestions included allowing unlimited selling of cars, being told up front the technology on the market, and having an overview of each company’s playing board.

There was also a unanimous agreement of students' enjoyment in playing the game. Their feedback around improvements focused mostly on position of the board so that teams would not be within sight of each other to create not only a cooperative team, but also a competitive environment. This was particularly interesting and reflective of this generation's style in that it demonstrated a paradox identified in the literature that students are competitive in the classroom and yet identify with teams and team work very strongly. It was interesting that students problem solved how to enhance this competitive/cooperative atmosphere. Individual learning style differences were expressed in areas of introductory instructions. For most, the instructions were helpful and clear; however, others described needing to experience a round of game play in order to make sense out of the game – perhaps a reflection of the trial and error style of this generation.

The largest area of suggested change revolved around the 5th quarter round. The students did not understand the purpose of the "sell off", and this created problems that were not anticipated by teams. There were also suggestions of more graphic directions (visual learners) or a comprehensive rule book for each team, which was again valuable information for a computerized version.

The Current Event cards were uniformly agreed to be clear and concise with little change needed except for the suggestion of more variety in the cards. The feedback on the Innovation Cards was less uniform. While many students found them clear, there was some feeling that these cards needed to provide more choices or be worded differently, that some did not make sense in the context of playing, or that some were unnecessary.

The budget worksheets to record expenditures and profit seemed to be another positive aspect of the game. Student's opinions varied from "helps a little" to "helps a lot". But one-third of the participants felt that doing the worksheets helped them to better understand the overall concept of supply chain and the environment.

Feedback on the team roles showed that students felt that the roles need more definition and clarity. Students felt overlap existed between the roles and some felt their role as environmental or R&D manager left them with little to do. The CEO role seemed to dominate and be the most active.

Focus Group

The strongest theme resulting from the focus group (held one week after the game) was student perception that the game helped them more with the teamwork/communication aspects of supply chain than engineering or technical concepts. As one student said "it [Shortfall] was strong on teaching people skills". This led students to suggest that an improvement would be to make the computer version more realistic and more complex.

Another suggestion was to make each team an OEM company that needs to work with the same [non-player] supply chain, instead of each team representing a different part of a single chain. As one student stated, "in real life they [companies] work together in supply chains because they all want to make money" and thus the competition in the game was somewhat unrealistic. Students also pointed out that in the final round everyone could sell off their company inventory and that the manufacturer could not lose, but "in real life it would be hard to sell".

Another strong theme was the perception of *Shortfall* as a learning method. Almost unanimously students felt that it would function as a "lab", that is most students felt they

needed an introductory lecture first explaining supply chain concepts, and then playing the game would solidify the concepts. This was interesting because it contradicted some of their program survey feedback about the need for some learners “just experiencing the game”. It also was contradictory to some of the research on learning style of the Millennials, though students may have seen *Shortfall* as an educative activity as opposed to a game activity and thus applied their experience of traditional learning models to their debriefing. They also commented on the lack of ability to find needed information quickly during the course of the game and this may have accounted for the students feeling that a content framework would be needed first to successfully play the game. A well-organized manual with superior index capability would allow “just-in-time” information retrieval on demand for students.

When asked to think about the process they went through to make strategic decisions during the game, students again identified that the initial rounds were devoted to “learning the game” and only after they understood how to play could they begin to play strategically. It also appeared that the strategic aspect depended on how the CEO in each team functioned: some appeared to be more democratic and some more authoritarian. As students discussed roles, it became clear that the CEO role was confusing and that the R&D and Environmental Manager roles were not developed enough to be effective. Some students in these roles said they “became bored” and learned less because they had less to do, thus supporting the theory that the Millennial students need to be constantly engaged by progressively more difficult problems – or in game speak, they have a need to “level up”, meaning a “rebalancing” of player roles is necessary.

Limitations

The pilot study provided important information about converting the prototype board game to a computerized version. However, there were a number of limitations to consider. First this was a self-selected group of students who agreed to meet out of class and the grade point averages of participants were in the higher range than an average class at the university. The study was also confined to a time limitation of approximately 90 minutes which did not allow for more than 5 rounds of play. This restricted time limited the amount of knowledge, skills, and confidence that could be measured and also led to the decision to design the Knowledge Survey more toward knowledge, comprehension and application. We only had two-thirds of participants return for the focus group and post test one week later which provided even smaller comparison numbers.

We also did not have a comparison group who were taught in the more traditional lecture based manner to compare knowledge, skills and attitude perceptions. This would need to be part of follow up studies as we feel from the preliminary results that attitude and interest in the topic would be enhanced with a game design.

While we realize that the generalizability of the results are limited because of the small number and self selection, the pilot did provide some insight and some interesting data to reflect on as we conceptualized the design for the computerized version.

Future Plans

Based on the play test and focus group, we have determined that students can experience the ramification of design and manufacturing decisions on the triple bottom line through the

game's simplified supply chain. Further, students reported unanimously that they enjoyed learning through this unique educational format.

After reflecting on student comments, brainstorming by the team has led to the conceptual design of a networked computer version of the game titled *Shortfall Online*. By expanding this board game into a network-based computer game, we expect to 1) raise environmental awareness in decision making, 2) create a platform which will allow dissemination of an educational game that initiates and promotes real student learning, and finally 3) extend the learning objectives and their impact to greater numbers of students.

The computer version of the game now under development, employs logic and mechanics similar to the board game, but takes advantage of the computer's ability to animate the business processes and environmental impacts, and to record and calculate public and private information for each team. Undergraduate students Seth Sivak and Mark Sivak spent the spring semester of their senior year creating a digital prototype of this game, the next step towards the final networked version. *Shortfall Online* will be designed to be played across the Internet; students need not be in the same classroom or even at the same school to collaborate and compete as a team in a game. Faculty and students can "reserve" an online "game room" for a specific time with specific players invited to play, or students can form a "pickup game" with others who may be waiting online. Although we expect that the game would be used primarily in the classroom, it will be designed to be playable without a human facilitator.

In the computerized version, more than one team can compete in the same tier of the supply chain; the computer will always provide at least one competing company in each tier of the supply chain so that the human teams have an incentive to work together to "beat the computer". A single game could support as few as two players working against the computer, or an almost unlimited number of human players competing in supply chain teams of three to six players (We suggest a logistical limit of 36 simultaneous players, based on early testing with nearly twice this number). Similar to the board game, the overarching purpose of the networked version of *Shortfall Online* is to demonstrate the importance of taking environmental issues into account when making design and operational decisions. The expected benefit of the computerized version of the game is that the environmental impacts and the range of decision-making situations can be expanded dramatically. By removing the need for students to perform manual calculations, it will be easier for them to focus on studying their alternatives before making decisions. In fact, the ability to make future projections with the help of the computer is planned as part of the next version impacts and the range of decision making situations can be expanded dramatically. We also are using a more rigorous evaluation technique in the area of millennial learning styles which we believe will provide valuable data for educators in designing lessons for this generation.

In *Shortfall Online*, we plan to create a more detailed simulation of the economic and environmental factors that have an impact at all levels of the automotive supply chain. 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. The game projections will be based on actual engineering data, but simplified to fit within the parameters of the game. A "plug-in" 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 Online*

game engine will present the results of player actions in the context of real-world scenarios that are drawn from a database. There will also be more to the scoring than just profit. Instead, the score is planned as a composite of three factors, of which the company's bottom line is only one: the other two are the company's environmental friendliness ("green index"), social score (as determined by responses to current events in play and interactions with other players). In addition to these three factors, which reflect the "triple bottom line", students should also score better based on their overall knowledge, as technological innovations and current events will require students to answer real-world questions.

Summary

In summary, engineering education must not only produce technically grounded graduates, but also graduates who are prepared to work in a constantly changing global economy. This was reiterated in a National Academy of Engineering Report (National Academy of Engineering, 2005), which recommended introducing interdisciplinary learning in the undergraduate curriculum. To create a culture for change in industry, engineering students must 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.

While the Millennial Generation of learners does pose challenges to current educational learning models, the concept of using "gaming" is a legitimate learning method for a new generation of students. Results from the pilot board game suggest that students not only benefit in the cognitive realm of knowledge acquisition, but also in the more neglected affective domain of learning by providing increased confidence in knowledge, engagement through appealing to a generational difference in learning style and finally by providing an active and engaging learning environment. Our hope is that *Shortfall Online* will create an interdisciplinary, technological, and student-centered networked design needed to provide a learning tool that will not only appeal to students, but will provide a forum to connect concepts in applied virtual situations which will increase student retention, sustain motivation to learn and ultimately increase learning.

Engineers will play a critical role in addressing the challenges of future sustainability. As mentioned, environmental issues are not "cut and dry" problems with simple answers; rather they are interconnected with technological and economic constraints. By enhancing economic and environmental literacy among engineering students through innovative pedagogy such as *Shortfall Online*, future engineers will be better prepared to meet these challenges and be cognizant of their obligation to the planet.

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