AC 2010-1860: ASSESSING THE EFFECTIVENESS OF USING A COMPUTER GAME TO BRIDGE A RESEARCH AGENDA WITH A TEACHING AGENDA

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Assessing the Effectiveness of Using a Computer Game to Bridge a Research Agenda with a Teaching Agenda

Abstract

We assess the impact of an out-of-class computer game designed to develop students' understanding of complex tradeoffs among environmental, economic, and technological issues. By comparing the results across three different courses using survey, essay, and focus groups as instruments, we measure the game's success in a variety of contexts and dimensions. Students increased their self-assessed knowledge about the supply chain and teamwork in the supply chain, they made connections between the environment and business practices as well as external events and the supply chain, but they did not feel that their understanding of sustainability improved. Students in an economics class experienced less increase and knowledge and confidence than did students in either an introductory policy class or a values-oriented course about built systems.

Research Question

Academics who care about both teaching and research are continually seeking ways to effectively integrate the two. Those who pursue National Science Foundation (NSF) funding often wrestle with this when answering the question: *What are the broader impacts of the proposed activity?* NSF asserts that the broader impacts criterion speaks directly to NSF's mission, "*To promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense."* (NSF Act of 1950). The NSF Grant Proposal Guide suggests several ways that this criterion can be met. One of these is "*by advancing discovery and understanding while promoting teaching, training, and learning"*. In response, researchers typically describe the number of students involved in the research project as evidence. Another suggestion by NSF is to *broaden dissemination to enhance scientific and technological understanding*. Here, researchers often describe plans to present research results in formats useful to students, scholars, members of Congress, teachers, the general public, etc. In other words, it is common for researchers to point to activities that involve student education as evidence that there are broader impacts to their technical research projects.

Faced with this challenge in our own research, we are following a different approach to achieve these education-related broader impacts. We suggest that we can successfully bring our research concepts into our traditional courses without unduly modifying the established course content. To accomplish this task, we use an out-of-class, self-directed computer simulation game by which students are expected to gain introductory knowledge of the research concepts as they "play" the game. We then draw connections between what they learned from the game and what they are learning (or not) in the course. Our hope is that this experiential form of learning can serve to bridge our research and teaching goals. To determine the effectiveness of this approach, we perform several student assessments centered on the question: *Can students achieve a set of learning outcomes by playing a self-directed, out-of-class computer game?* The remainder of this paper explains the research and grounds the work in relevant literature, describes our approach to assessment, and reports the results of assessments conducted during academic year 2008-2009.

Background

By asking students to use a computer simulation game to gain knowledge about various research concepts, we are in essence placing them in a context where they learn by making decisions and seeing the consequences of those decisions; in other words, they learn from the experience. To reinforce the concepts, the game is designed so that students repeat this decision-making process over 10 rounds of the simulation while also interacting with team members (peers) to make the decisions. Our decision to use a game as well as our choice of the game itself is grounded in the literature of learning strategies. The following sections review these theories, describe the game we have incorporated in our courses, and provide some context for the larger project of which this effort is a part.

Learning Strategies and Educational Games

Behavioral, cognitive, constructivist, and experiential theories of learning have influenced the design of learning activities, including educational games and simulations. The following paragraphs briefly review what is known in these areas of inquiry and relate them to simulation exercises in general and our work in particular.

Behavioral theory is based on the belief that we learn that certain behaviors are good (or bad) based on the rewards, and/or punishments we receive for repeated actions; in other words desired behavior is repeated until it is learned.[1] Skinner (1976) suggests that students learn better when they are forced to practice certain actions until they reach mastery.[2] The behavioral theory of learning became a key part of the early design of technological teaching aids (including simulation) for the military because of the ability to ask the user to repeat tasks multiple times.[3]

Cognitive theory assumes a learner observes desired behavior along with indicators of why this behavior occurs; these indicators and the subsequent understanding can then be used by the learner to duplicate this behavior.[4] A key part of the cognitive theory is that corrective feedback must be provided as part of the exercise to help users understand *why* their actions worked, or failed, and to retain that information.[5,6] In other words, students not only have to gain information in simulations, they also have to critically evaluate that information as part of the exercise.[7]

Constructivist theory is a combination of theories that suggests students learn by doing rather than by observing; these students bring prior knowledge to every learning situation, which must be rebuilt as they gain new information.[8] Piaget (1977) believes that teachers are there to facilitate individualized learning with students who need to be provided with many opportunities to experiment, discuss, and debate the various concepts.[9] Vygotsky et al. (2006) went further to suggest that students can only go beyond their individualized state of knowledge if an instructor guides the process; this guided stimulus is needed for full learning to occur.[10] Simulations can provide an ideal context for students to construct and reconstruct their beliefs about dynamic situations with new information.

Kolb (1984, p. 41) describes experiential learning as "the process whereby knowledge is created through the transformation of experience."[11] This experiential learning process is a four-stage cycle where a learner observes and reflects on a concrete experience, these reflections are transformed into abstract concepts, these abstract concepts suggest new ideas, and these new ideas are then tested so they can guide new experiences.[12] Central to the theory is that learners have different learning styles, and make different choices in educational settings.[13]

These learning theories are used to design appropriate simulation exercises depending on the level of the learning objectives and the existing knowledge of the students. Ertmer and Newby (1993) suggest that behaviorism works best for introductory learning with students who have little prior knowledge about the learning goals, and there is sufficient benefit from the repeated practice of concepts.[14] In contrast, they suggest that cognitivism should guide the design of simulations where the instructor wants students to process the concepts at a higher level of evaluation and to do this, students need to differentiate between relevant and irrelevant information.[15] Where students must make decisions that depend on significant information processing and prior knowledge, the authors suggest that a full constructivist approach should be used to design the simulations.[16] Instructors following experiential learning theory know that in a classroom of learners with different styles, simulation exercises must be flexible for the user.

The design of most instructional materials/tools is based on a mix of behavioral and cognitive theories.[17] However, similar to the development of learning theories over time, computer "games" for learning evolved from drill-and-practice exercises in the 1950s and 1960s, to the use of cognitive science in the late 1970s, to the constructivist approach starting in the late 1980s and 1990s.[18] With the constructivist approach, users of the computer games have some level of control over their learning, *and* these users reflect on what they have learned and what they still need to learn.[18,19] Regardless, the best learning approach (or mix of approaches) for a computer game depends on the particular context, learning objectives, and student population.[20]

A recent article emphasizes that the current generation of students are used to the "open-ended, highly responsive environments represented by next generation games."[21] A survey of MIT freshmen concluded that 88 percent played video/computer games before the age of 10, and 75 percent of them are still playing these games.[22] Therefore, educational games must be developed with adequate resources in terms of both pedagogy and entertainment.[23] Whitton's (2007) study supports this statement since she found that students do not find educational video games particularly motivating.[24]

Well-designed computer games provide students a context to "experience" the issues, make flaws in students' existing knowledge apparent to the student and to the teacher, and allow students to reflect on the experience to promote new learning. [25] Instructional game designers accomplish these goals by asking students to make choices in the game based on their existing understanding of the particular context, allowing them to see the consequences of those actions, motivating them to find the additional information needed to improve these choices (information literacy), and encouraging them to collaborate and learn from each other.[26,27]

The Shortfall Game

We use the game *Shortfall*, developed by researchers at Northeastern University. The goal for Northeastern's project is to create an innovative tool to educate future engineering leaders by *developing their understanding of complex tradeoffs among environmental, economic, and technological issues*. Shortfall is a cooperative, cross-disciplinary computer simulation game developed by Northeastern faculty and staff from three departments: the Department of Mechanical and Industrial Engineering, the Department of Visual Arts and Multimedia Studies, and the Department of Education. In an effort to extend the educational impacts, and to gain more feedback, Northeastern faculty are actively cooperating with other institutions. The synergy between Northeastern's goals and those of our research team make this an attractive partnership.

Shortfall was initially developed as a board game, and then into a computer simulation game that will ultimately be networked over the Internet. The game is played with teams of students representing stakeholders in the manufacturing supply chain for the automotive industry. In its non-networked computer version, students create a team of three suppliers: materials, parts, and cars. Within each team, one or more students take on the role 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 for production, storage and waste disposal. The game includes tradeoffs in investment costs and green values for each technology option, with a hierarchy for the technology options. During the ten rounds of the game, the students work within their team and budget to try to create the most profitable and green supply chain. An "event" occurs after each round that affects various considerations related to the supply-chain decisions such as a downturn in economy, employee labor strikes, etc. Student supply chain teams compete with other student supply chain teams. Successful game strategy requires both cooperation and competition for players to succeed. Shortfall is described more fully in a 2008 ASEE conference paper.[28]

Shortfall is essentially a constructivist game where students participate in the supply chain, making decisions initially based on their own knowledge, and then based on their observations of the results of those decisions (and the random events) which leads to their reconstructed knowledge. In addition, students are free to research the various technologies to reconstruct their knowledge based on more than just observations of game situations. Shortfall also includes aspects of behavioral theory in the repetition of the decision processes for the 10 rounds.

The Environmental Policy Research Project and Participating Courses

In summer 2007, we received a grant from NSF to develop improved tools for environmental policy-making by combining life-cycle assessment and strategic market analysis in a simulation context. As stated, the project meets the "broader impacts" criterion via self-contained educational modules used as part of more traditional policy, social science, and engineering undergraduate courses. Shortfall, the self-contained computer simulation game developed by Northeastern University, serves as one of these modules. The specific outcomes that we originally aimed to achieve with this computer simulation game are that students can describe, at an introductory level, the following:

a) environmental and economic sustainability issues,
b) how individual firm decisions collectively affect supply-chain decisions (referred to as market interaction),
c) how computational methods can be used to assist policy decisions, and

d) the effect of complexity on decision-making.

The courses in which we have implemented the game are taught by the authors and include one from Engineering Studies, Introduction to Engineering and Public Policy; one taught under the rubric of Values and Science and Technology (VAST), Sustainability of Built Systems; and a Marketing Research course from Economics. The game and assessment methods were piloted in Fall 2008 in the Engineering Studies course and then used in Spring 2009 in the VAST and Economics courses. None of these courses include topics directly related to the Shortfall game, i.e., the manufacturing supply chain in the automotive industry. In addition, although some class examples and group projects touch on environmental policy and basic economic principles, these topics are not formally treated in these courses. In other words, any student knowledge about the manufacturing supply chain for the automotive industry, and the associated issues of collective decisions, computational methods, and complexity derives from these students' existing knowledge separate from the course, and/or Shortfall. However, unlike the Engineering Studies and Economics courses, which did not directly address issues of sustainability, the VAST course was focused on sustainability issues, but in the context of built systems rather than manufacturing.

Assessment Methods

In developing the assessment, we have multiple objectives. Researchers at Northeastern are interested in how well Shortfall is designed in terms of user-friendliness, and learning outcomes (*understanding of complex tradeoffs among environmental, economic, and technological issues).* Our research team is interested primarily in the four specific learning outcomes directly related to our research project (*sustainability, market interaction, computational methods, and complexity*). Three of these four learning outcomes are directly related to those of Northeastern, however they are somewhat more specific. The Shortfall game also refers more to *environmental* impacts than to *sustainability* impacts. The computational methods outcome is indirectly related to Northeastern's learning outcome, at best. Given the multiple assessment objectives, we used the following methods: a) pre- and post-surveys that are modifications of those developed by Northeastern to gauge student knowledge, student confidence in that knowledge, and students' perception of their knowledge; b) pre- and post-game reflective essays we developed to assess the students' initial knowledge and reconstructed knowledge after playing Shortfall; and c) focus group questions developed by Northeastern about the usability of the game.

Surveys

The survey questions are listed in Tables 1 and 2. The pre- and post-surveys are identical, except that the pre-survey includes a preliminary set of questions on the students' personal preferences regarding teamwork and video games, and demographics. Approximately half of the remainder of the survey focuses on a direct measure of student knowledge, and self-assessment of student confidence of that knowledge. The other half of the survey includes Likert questions that ask students about perceptions of their knowledge, with a scale of strongly agree to strongly disagree. A few of these questions also ask students about their comfort level with teamwork (questions 9-11 in Table 2); on reflection, this section seemed out-of-place in the survey so we did not include it in the results, and we removed it after the pilot. We did not change the knowledge/confidence questions on the Northeastern survey; however, we added a few questions

(questions 5-8 in Table 2) to the perception questions specific to our learning objectives. We chose to only track the students' answers to the confidence and perception questions. We report the results across the aggregate of all students evaluated and separately by course, with comparisons between them.

We did not track students' knowledge; asking the students to actually write answers to the questions in Table 1 is meant to improve their ability to accurately gauge their confidence in their answers. In other words, the survey portion of the assessment studies how students think playing Shortfall affected their own knowledge, not how it actually affected their knowledge. As described in the literature, students must value the experience of playing the computer game for it to be an effective teaching tool.

Table 1. Survey - Knowledge Questions (and confidence with the answer)

1.	Identify two characteristics of a successful supply chain.
2.	List two specific environmental issues associated with manufacturing in an automotive supply chain.
3.	Identify two Federal government regulations (at least one environmental regulation) that affect automobile manufacturing.
4.	Name two practices for reclamation of waste or pollution reduction in manufacturing processes.
5.	Identify two technology upgrades in a manufacturing facility that could make operation more environmentally friendly.
6.	Name three events (external to the supply chain) that can impact business practices.

Table 2. Survey – Student Perception of Knowledge Questions (as used in the pilot; questions 9-11 were subsequently removed)

1.	I am knowledgeable about the automotive supply chain.
2.	I am knowledgeable about supply chain management.
3.	I am knowledgeable about manufacturing practices.
4.	I am knowledgeable about environmentally benign manufacturing practices.
5.	I am knowledgeable about sustainability issues.
6.	I am knowledgeable about how individual firm decisions collectively affect the sustainability of supply-chain decisions.
7.	I am knowledgeable about the use of computational methods to assist policy decisions.
8.	I am knowledgeable about the effect of complexity on policy decisions
9.	I work well on teams in which I have a leadership role.
10.	I work well on teams in which I have a subordinate role.
11.	I prefer to work individually when possible.

Essays

As stated, we added a pre- and post-game reflective essay to the overall assessment method so that we could directly assess the students' knowledge of the research concepts and whether that knowledge was reconstructed as a result of the computer simulation exercise. We believe that this is an important part of the assessment since the students have little prior knowledge about the topics, and limited to no formal instruction on these topics in this course. Reflective essays are typically used to encourage self-assessment, provide feedback soon after an exercise is completed, and do not require much additional student time.[29] The essay question asks the students to apply some of what they used in the computer game to a different context described in the essay question. The essay is completed by hand, during 20 minutes, on a maximum of one two-sided page. The initial version of the assignment asked students to address all four issues of interest (sustainability, market interaction, computational methods, and complexity) in the context of regulating the supply chain for a "new consumer good." As a result of the pilot, we simplified the assignment, asking students to address only sustainability and market interaction and to do so in the context of the automobile supply chain (the same context as Shortfall). The final version of the essay assignment (post-game, with language used in the pre-test in brackets) is as follows:

> *During this course you have completed [will complete] a computer game that shows you how the issues of* ***sustainability*** *and* ***market interaction*** *affect the effectiveness of environmental policies. [Before you play the game, we'd like to see how much you already know about these topics.] Please describe how these* ***2 issues*** *affect the policy scenario below. Be sure to* ***define*** *each of the issues, and* ***explain*** *how they each affect the scenario using only the space provided (front and back of this sheet).*
>
> *Policy Scenario: A regulatory agency recently adopted the goal that all new regulations will advance sustainability. The agency must now decide how to regulate the automotive supply chain (or parts of it). Explain how the agency should approach this task in terms of 1) sustainability, and 2) market interaction. We are interested in your recommended approach to solving this problem, not the final decision, since you do not have enough information to make such a decision.*

A student assistant typed each essay into a word processor, and we did a keyword search for several pre-identified indicators of the various research concepts (except computational methods). We then compared the number of keywords for each of the research concepts both pre- and post-game across the aggregate of all students. We also evaluated the number of students who were able to discuss some of these concepts before and after playing Shortfall. The keywords/phrases (at an introductory level) are as follows according to three of the four learning objectives (not computational methods); searches were performed on various forms of the words, as appropriate:

- Describe sustainability (environmental and economic) issues: *least possible non renewable resources use, air/water/land pollution/waste/emissions, energy use, human health and ecological risk; regulatory compliance, best management practices, externality(ies), wealth per capita, net present value, willingness-to-pay, willingness-to-*

accept, benefit/cost ratio, inter-generational transfers, first/initial costs, recurring/annual costs, discount rate, cradle-to-grave, life-cycle, efficiency

- Describe how individual firm decisions collectively affect the sustainability of the supply chain (market interaction): *common pool, prisoners' dilemma, rational, game, satisficing, Nash, demand, uncertain, work together, change, cooperate*
- Describe the effect of complexity on decision making: *connected, inseparable, insufficient information, system*

Focus Groups and Class Discussion

The Northeastern focus group questions are designed to assess the game's user-friendliness. We did not make any changes to these questions other than describing the research concepts in terms of our specific project. We administered the focus group questions in class on the day the assignment was due, and after the surveys and essays were completed. One of us asked the main question and follow-up questions, while another recorded the answers. We did not ask the questions in a particular order, but adjusted based on student responses. However, we tried to ask all of the questions in the allotted time. During the discussion, we tried to make connections between the research concepts and courses students may have had in the past or may take in the future. Within a few days of the discussion, we reviewed the typed information, and reorganized the responses according to the questions. The questions are listed in Table 3.

Table 3. Focus Group Questions on User-Friendliness

1.	What is your impression of the game as a method of learning about the topics?
2.	How could the game be improved? How could the game better incorporate the concepts?
3.	What knowledge or skills would you need prior to playing the game?
4.	Looking back, describe the process of how you made strategic decisions during the course of playing the game.
5.	How do you see Shortfall fitting into a course? Would it be appropriate as a substitute for a lecture, an extra credit to a lecture, a lab for the material?
6.	Do you feel you could learn everything you needed to know about the concepts of sustainability decisions for product supply chains at an introductory level from just playing the game?
7.	What's the most important thing you learned from playing the game?

Discussion of Results

For all three classes, we assigned the game as an out-of-class homework assignment to be completed by groups of students anytime within a 48-hour period. The students had worked in these groups before; this ideally avoided any issues associated with initial comfort levels regarding teamwork styles. We did not provide any preliminary information about the game or the game concepts other than to direct the students to the online version that includes instructions for playing, as well as a tutorial. There was no penalty if students did not do any additional research on the various technologies and "events." Before the assignment, students completed the pre-assessment for 30 minutes during a regularly scheduled class. For the initial implementation (in the engineering policy class in Fall 2008), the entire class session on the day the assignment was due was devoted to the post-assessment, including a lengthy group discussion of the students' experience. We modified this procedure for the other classes so that they completed the pre-assessment, played the game, participated in the focus group discussion, played the game a second time, and then completed the post-assessment. This required a total of approximately 2 hours of class time over three class periods.

Pre- and Post-Survey

The pre-survey provides information about the demographics of the students. Approximately one-quarter of the students (17 of 61) are female, slightly over half (34 of 61) are completing an engineering major, and one-third (20 of 61) are completing an economics major (many students in all three classes have two majors). More than half of the students (35 of 61) were sophomores, 17 were juniors, and 9 were seniors. The mean reported GPA is 3.1. The students display a fairly even mix of learning preferences. The results also show that the students use a range of strategies to both complete homework and team projects. All of the students indicate they have some willingness to cooperate with competitors for long-term benefit even if there is some short-term cost, though almost all note that this decision depends on its context. Over 75 percent of the students indicate that they are strongly concerned about the environment.

Our analyses below were run as both ordinal probit and ordinary least squares (OLS); although the latter is standard in the survey literature that assumes an interval scale, the former recognizes that the ordinal scales are more realistic. When results for the two are similar, as they are in this case, interpreting the results of OLS is simpler because the estimated coefficients are the marginal effects.

<u>Demographics and attitudes.</u> Based on the personal preference questions on the pre-assessment survey, we looked at the relationship between our students' majors, gender, and the three questions that regard cooperation and environmental issues. Although these questions are not the direct focus of this paper, they relate to the results and confirm some findings in the economics literature. The two questions are on a scale of ten, so coefficients in an OLS regression indicate the mean difference in the student populations' attitudes.

> *In making tradeoffs in a given situation would you be willing to cooperate with "competitors" if it might be to your short-term detriment, although it would be beneficial in the long term?*
>
> *Never 1 2 3 4 5 6 7 8 9 10 Always*
>
> *Does your answer depend on the situation? Yes _____ No _____ If yes, why?*
>
> *On a scale of 1 to 10, rate your level of concern regarding importance of environmental issues in general.*
>
> *Lowest 1 2 3 4 5 6 7 8 9 10 Highest*

Because we have economics majors (or double majors) represented in all three courses, we ran the tests both classifying anyone with economics as one of their majors as an economics student, and we also ran the results with only the students in the economics class classified that way. We found the correlation between gender and the answers to these two questions to be of only marginal statistical significance and not related to our other results. We report the results below at 95% confidence unless otherwise stated.

However, we did find that economics students are less likely to either cooperate or care about their environment, by a mean distance of about 0.65 on the 10-point scale. This is consistent with the existing literature on connections between selfishness and college economics majors.[30,31] The differences among the courses are also interesting. With regards to cooperation, there is no difference between the students in the engineering policy and economics courses, but students in the course with "values" in its name feel on average about 1 point of 10 more likely to cooperate than students in either of the other two classes.

The three classes differed in their opinion of the environment. Taking the economics class as a baseline, the engineering policy students are (with 90% confidence) 0.7 points of 10 more interested in the environment and the VAST students are (with 99% confidence) 1.4 points more likely than the others to care.

<u>Self-assessed Changes in Knowledge.</u> Student responses to these survey questions address the focus of our study: How effective is this simulation as a learning strategy? Table 4 shows the changes in student responses to questions about their confidence in their knowledge, and Table 5 shows changes in student responses to the questions about their perceptions of their knowledge. These results do not consider separately the students' responses before or after. Instead, we focus on how their responses changed as a result of playing and discussing the game. Thus we present the *change* in the distribution of students' confidence in (Table 4) and their perception (Table 5) of their knowledge.

The numbers reported in Tables 4 and 5 are the coefficients in an ordinary least squares regression, assuming interval scaling. Thus the changes in distributions are changes in the mean. We also ran regressions using ordinal probit to reflect the actual ordinal scaling of the variables, but the results were nearly identical, and these coefficients are easier to interpret.

In Table 4 the changes are on a 3-point scale, so those changes that are statistically significant are also relatively large, from ½ to over 1 ¼ points out of 3. Those changes that are not statistically significant also have smaller point estimates. A 1-point change, for example, means that students' confidence in their answers move on average a distance equal to that from "Not confident" to "50% confident" or from "50% confident" to "Confident" among the three points in the scale. In Table 5 the changes are measured on a 7-point scale, so they are smaller in relation to their scale than in Table 4, but they are still sizable. Those cells that are not statistically significant in Table 4 are again also smaller point estimates.

In all classes, students perceive that they learned about and are increasingly confident in their knowledge related to supply chains. There was less statistically significant movement among students in the economics class; this could be due to those students having more knowledge of supply chains prior to playing the game.

There are some contrasts between the courses, especially that the students in the economics course experienced less increase in knowledge and confidence than did the other courses, while the policy course's students had almost uniformly more increases in their knowledge. Relevant to this discussion is the final column in both Table 4 and 5. Note first that in all the cells of the Tables' first three columns there are only two negative coefficients. So we see that even when the results are not statistically significant for a single class (almost always VAST or Economics, which were both half the size of the policy class) but significant for another (almost always Policy), the point estimates of all three are still positive. Perhaps we have a noisier signal in the smaller classes. (There is one exception, question 4 in Table 5, where it is the VAST and Econ courses that have improvements, although their statistical significance is only at the 10% level).

The pooled samples in the final column of each table produces these findings: The group of students as a whole increased their self-assessed knowledge mostly about the supply chain (question 1 in Table 4 and questions 1 & 2 in Table 5), teamwork in the supply chain (question 6 in Table 5), and they made connections between the environment and some business practices (question 2 in Table 4 and question 4 in Table 5) as well as learning about external events that can affect the supply chain (question 6 in Table 4). Particulars were lost on them (questions 3, 4, and 5 in Table 4), and they did not feel that their understanding of "sustainability" (Table 5's question 5) improved.

Table 4. Changes in Students' Confidence in their Knowledge

	Mean Change on 3-point scale			
	Policy	**VAST**	**Econ**	**Pooled**
1. Identify two characteristics of a successful supply chain.	0.743** (0.176)	1.175** (0.213)	0.676* (0.262)	0.848** (0.123)
2. List two specific environmental issues associated with manufacturing in an automotive supply chain.	0.567** (0.165)	0.400 (0.264)	0.236 (0.184)	0.443** (0.115)
3. Identify two Federal government regulations (at least one environmental regulation) that affect automobile manufacturing.	-0.0267 (0.178)	0.000 (0.292)	0.0604 (0.309)	-0.00384 (0.137)
4. Name two practices for reclamation of waste or pollution reduction in manufacturing processes.	0.356† (0.199)	0.200 (0.249)	-0.192 (0.222)	0.175 (0.134)
5. Identify two technology upgrades in a manufacturing facility that could make operation more environmentally friendly.	0.000 (0.189)	0.333 (0.220)	0.0769 (0.233)	0.0997 (0.129)
6. Name three events (external to the supply chain) that can impact business practices.	0.500** (0.177)	0.519† (0.261)	0.231 (0.237)	0.451** (0.125)

Standard errors in parentheses, ** p<0.01, * p<0.05, † p<0.1.

Pre- and Post-Reflective Essays

The essays provide direct information about changes in students' knowledge of sustainability and market interaction as a result of playing Shortfall; the results using keyword analysis are inconclusive. For example, in the VAST class sustainability-related terms were mentioned much more frequently in the post-essay than in the pre-essay, but there was a decrease in the other two classes. However, the combined essay results show that overall, more students are knowledgeable about sustainable issues than about market interaction. This result is not surprising given the students' stated strong concern for the environment. Nor does this result contradict our findings in Tables 4 and 5 because those focus on changes in students' self-assessed knowledge. We did not see such *changes* in knowledge in the reflective essays. Further discussion of the use of essays as an assessment method follows in a later section.

Table 5. Changes in Student Perception of Knowledge

I am knowledgeable about:	Mean change on a 7-point scale			
	Policy	**VAST**	**Econ**	**Pooled**
1. the automotive supply chain.	1.227** (0.286)	1.825** (0.401)	0.769 (0.578)	1.285** (0.234)
2. supply chain management.	1.452** (0.305)	1.938** (0.447)	0.692 (0.506)	1.411** (0.235)
3. manufacturing practices.	0.516† (0.306)	0.537 (0.381)	0.0275 (0.477)	0.423+ (0.228)
4. environmentally benign manufacturing practices.	0.452 (0.356)	0.783† (0.426)	0.929† (0.468)	0.655** (0.245)
5. about sustainability issues.	-0.419 (0.289)	0.179 (0.242)	0.335 (0.407)	-0.101 (0.206)
6. how individual firm decisions collectively affect the sustainability of supply-chain decisions.	1.00** (0.280)	1.108** (0.357)	0.995* (0.474)	1.025** (0.205)

Standard errors in parentheses, ** $p<0.01$, * $p<0.05$, † $p<0.1$.

Focus Group and Class Discussion

The class discussion is useful in conjunction with the pre- and post-game surveys and essays because the three instruments combined demonstrate that students were consistent in their responses and had taken the assessments seriously. The discussion also shows that, overall, the tutorials and help screens make the game user-friendly. Finally, the discussion provides us with a better understanding of how the students interpret terms and understand certain aspects of the game. The discussion summaries generate the following observations:

- Students treated Shortfall as a self-contained game. They did not research aspects of the automotive manufacturing supply chain and related issues outside of the information provided in the game. For the most part, once they understood the general strategy to increase profit, they then repeated that strategy throughout without thinking about issues of sustainability, regulations, etc.
- Students did not understand how the green score (an indicator of sustainability) in the Shortfall game is calculated, nor did they feel they had a sense of what would constitute a "good" green score.
- Students wanted a logical connection between the "random events" and other aspects of the game.
- In our first implementation (in the engineering policy class), students indicated that they would have preferred to play the game a second time because they felt that the first time was a trial to "learn" the game. Students also expressed some interest in playing the game again after the class discussion because of the confidence gained from listening to peers and the instructor. These observations caused us to modify the structure for the later two classes.
- Students are able to discuss issues of cooperation and strategy as they relate to the three firms in the supply chain; however, a few students noted that taking certain intermediate economics courses would have been helpful. In general, students recognized that prior knowledge about both economics and sustainability was important.

- Reflecting our findings about differences in attitudes between the three classes, the comments from students in the economics class indicated that they were more likely to have assumed the game was meant to be competitive rather than cooperative, whereas discussions in the other two classes pointed out the importance of cooperation to success. In conjunction with this, they also discussed the importance of good communication. Unfortunately, we cannot classify the comments according to economics *majors* from the other classes to see if this attitude is associated with the particular course or the major.
- Students experienced "horizon effects;" that is, as they got closer to the end of the 10 rounds of the game, they changed their behavior because they know they had limited time remaining. They commented that this caused their behavior to be "less realistic."

On the whole, students' discussions indicate their perception that this exercise was about the environment and sustainable practices, but – as reflected both in the comments and in the statistical results – they aren't able to take away new knowledge about those issues unless they are related directly to the supply chain.

Lessons Learned

From Initial Implementation

The initial implementation in the engineering policy class in Fall 2008 confirmed that a mixed methods approach is useful for gaining a holistic understanding of the students' learning experience playing Shortfall. The test also showed some changes that were needed; we implemented these changes prior to the later two courses:

- Remove the survey questions (perception) about teamwork and video games because they are already asked on the pre-survey demographics sections, and do not have anything to do with the learning outcomes.
- Shorten the surveys to focus on just the learning outcomes relevant to our project to improve the thoroughness of the responses. At the same time, keep most of the original Northeastern questions to help with the overall assessment of Shortfall.
- Remove survey, essay, and focus group questions related to complexity and computational methods because these are not directly addressed by playing the Shortfall game.
- Revise the essay questions to focus on just sustainability and market interaction in terms of the automotive manufacturing supply chain to determine if the students gain knowledge (rather than just perception of knowledge) after playing Shortfall. It is difficult to determine why the results of the pilot are inconclusive, however one reason may be that it is difficult for students with introductory knowledge of the technical concepts to transfer them from one application to a general context. Another reason for the inconclusive results may be due to including too many technical concepts in a short time period for responses.
- Change the assessment procedure to include: pre-assessment, the game, focus group discussion, repeat the game, post-assessment. This assessment procedure better integrates the constructivist and experiential theories of learning as the students reconstruct their knowledge several times: a) while playing the game the first time, b) after gaining more cues from the reflection that occurs in the class discussion, and then c) after playing the game a second time.

From All Three Assessments

The Methods. We continue to find the mixed methods approach valuable, particularly the surveys and the focus group discussions. The essays have been more problematic. The questions need to be refined to better reflect students' varied backgrounds. Further, the evaluation method we have used (keyword analysis) has not yielded useful results. A more detailed evaluation that assesses the sophistication of students' answers may be more helpful.

The Game. The results suggest that more design work is needed by the game developers to connect the green score with student strategy, and the random events with student strategy. The game also needs to better encourage students to research the key concepts on their own as they progress through the game. In addition, the developers should consider the impacts of horizon effects on students' behavior.

Students would like more feedback on the consequences and value of their actions. Although our assessment method helps them critically evaluate information, the Shortfall simulation provides little of the feedback specified by cognitive theory. Our students want to move to this higher level, but find it hard to know what is relevant.

Consistent with constructivist theory, we find evidence that prior knowledge is important, as well as the context of the class for which the simulation is required. This may be the most important level in which simulations work: contextualizing students' knowledge.

Bridging Research and Pedagogy. The overall reason for asking students to play Shortfall is to introduce them to the key research concepts that are part of our NSF project. Shortfall appears to help students learn about market interaction and sustainability concepts as they relate to a specific supply chain. The same is not true for learning concepts about computational methods and complexity.

Future Work

The Shortfall development team at Northeastern has continued its work on the game, moving from the current prototype to a networked implementation. Several aspects of the game have been redesigned for the networked version, based on assessment of play test at Lafayette and at Northeastern. The design change that is most significant to this reported work involves revisions to the scoring aspects of the game. Both student and faculty feedback indicated that the scoring system (based primarily on overall profitability) was the weakest part of gameplay – both in terms of game enjoyment and in terms of learning. The original scoring system did not provide a driving force to learn more about the tradeoffs between or among the three pillars of sustainability. Hence the scoring system has been revised for the next version of the networked game to enable students to set their own winning conditions based on the three pillars of sustainability: financial, environmental, and social. An overall performance score will be computed based upon a normalized, linear-weighted aggregation of these three underlying criteria. The criteria weights, which balance the game play objectives among the three objective criteria, will be self-selected by the team members themselves prior to the game, such that they will "play to win" in the categories of higher weighted value. Teams need not select the same weight set to compete against one another, as different teams may have different objectives and still be assessed competitively on the overall scale. Nonetheless, normalization of performance on each criterion will be relative to performance of the entire "industry" playing. It will be interesting to assess how students in different disciplines value sustainability in this way, and these changes will allow students to test out whether they can win under alternative conditions. It is hoped that this change encourages more learning and reflection on the tradeoffs among the tenets of sustainability.

We will revise the assessment plan as we continue to incorporate and evaluate Shortfall in these and additional courses at Lafayette. The opportunity to compare assessment results for a larger sample size of students with different backgrounds and in different contexts should provide richer results. We will continue to provide the results of our assessments at Lafayette for consideration by the Northeastern team in its ongoing development efforts.

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