

Interactive Simulation for Teaching Engineering Economics

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Abstract

A game involving the selection of investments has been integrated into a course on engineering economics. The game challenges students to not only learn engineering economic principles such as present worth, but also to use them to make realistic economic decisions in a competitive setting. Each student starts with

\$10,000, and is presented with a list of investment opportunities. Students apply the principles learned in class to the possible investments and make decisions, such as how much to bid on a particular mine or factory in an auction. Additional investment opportunities are introduced weekly throughout the semester, with the required analysis growing in complex-

ity as the students' knowledge base increases. The game is interactive; for example the owner of a factory must negotiate the price of raw materials he/she needs with the owner of a mine. Student response to the exercise was extremely positive; they found it both enjoyable and beneficial.

Introduction

Recent texts on engineering economics¹⁻⁴ all stress that the practical purpose of engineering economics is that it empowers the engineer to make sound investment decisions. End of chapter homework problems in these texts can be broadly placed into two categories:

- 1) Strictly computational problems, such as "calculate the rate of return of this cash flow diagram," and
- 2) Questions such as "should the equipment be replaced or not?" or "Which of these three possible designs is best?" that ask the student to make a practical decision.

The inclusion of some problems from the latter category is crucial both because they provide the more thorough test of the student's understanding of the material, and because they underscore the practical value of the material.

This paper describes a game that simulated practical economic decision-making. Students started the semester with \$10,000 and "ran their company" throughout the semester, applying the principles learned in class to a series of possible investments presented by the instructor. The game thus filled the role of the traditional homework problems, but had some additional goals and benefits:

- ◆ It created a framework for active learning of the material. Students had to not only learn various economic analysis techniques but determine which ones

were most applicable to the case at hand.

- ◆ It created a classroom environment that was fun, relaxed and informal while still being instructive.

- ◆ It allowed students to see first-hand some business world phenomena, such as monopolies, that aren't necessarily part of the traditional engineering economics course.

- ◆ It exposed students to some human challenges in economic decision-making that traditional homework problems would not.

These are discussed further in the Assessment of Simulation section below.

The game described in this paper was integrated into a senior/graduate course on engineering economics in the spring of 2001 and spring of 2002. This course was an elective, open to all engineering disciplines, with enrollments of 12 and 8 students in these two semesters. Chemical, mechanical, electrical and civil engineering were all represented in the enrollment. The class met once a week, in the evening, for two and a half hours. A typical class period was broken into two ~50 minute portions during which new material was presented through lecture and example problems, with a break in between for activities (auctions etc.) related to the game.

The following sections describe the game in more detail, discuss how it was integrated into the class, and summarize student response.

Description of Simulation

Figure 1 summarizes the content of the course in the order it was presented, and outlines the investment opportunities that were intended to reinforce each of these concepts. This section explains the mechanics of the game and provides details about some of these investment opportunities.

Possible Investments

Each student started the game with \$10,000. The semester was divided into twenty turns. The stated goal of the game was to finish turn 20 with as much cash as possible. Thus, all investments had a fixed, known planning horizon (and no salvage value unless otherwise stated). Students were given the option of placing money in a savings account- with no minimum or maximum balance and no restrictions on frequency or size of withdrawals- at 5% interest per turn. In addition, students had the option of borrowing an unlimited amount of money at 15% interest, compounded every turn.

Many investment opportunities were introduced into the game through auctions. Students received handouts describing the specifications for each of the assets that would be auctioned off in future class periods. They then applied present worth analysis to these assets and prepared a bidding strategy. Auctions were carried out during class using a sealed-bid format; each student wrote

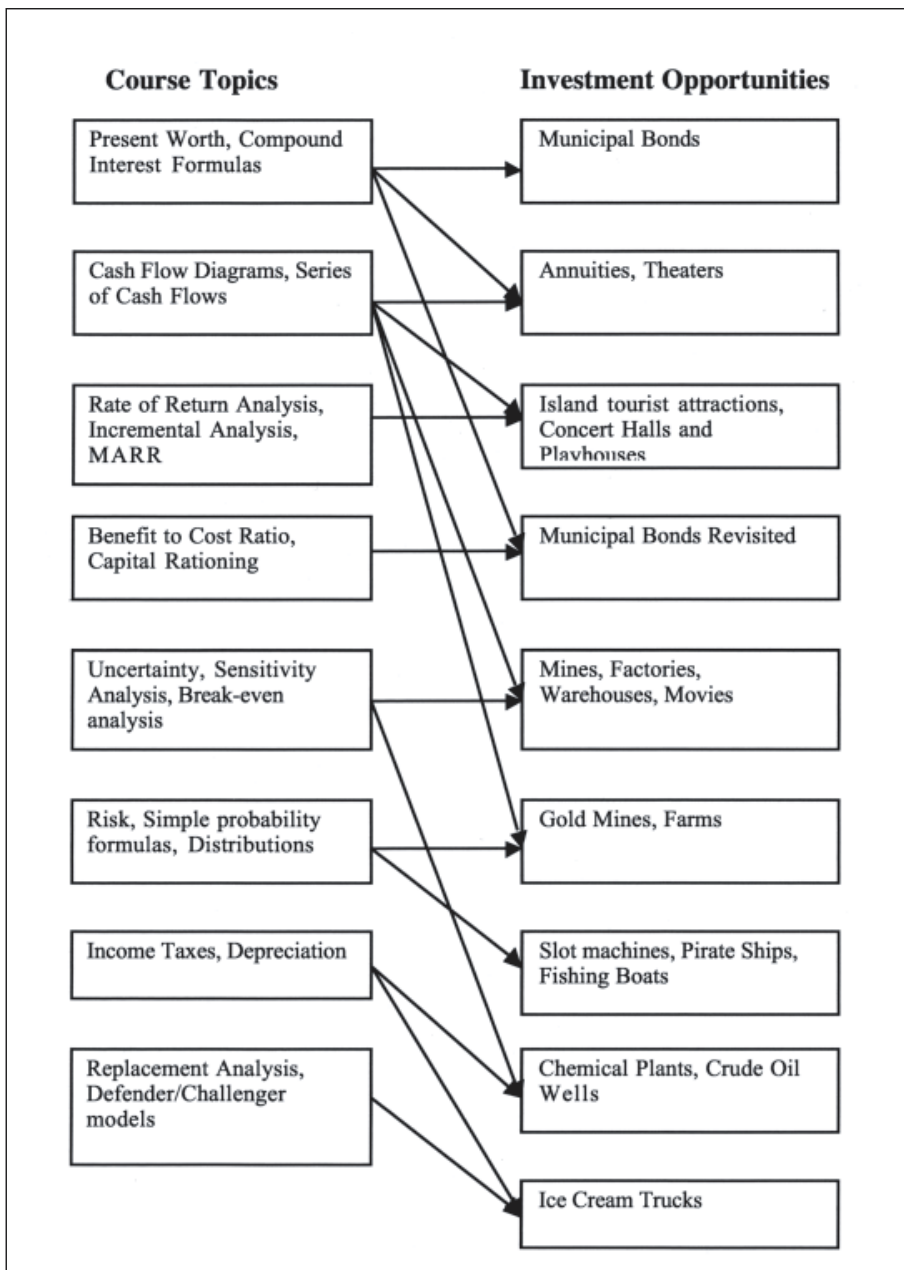


Figure 1. Summary of major course topics and the investment opportunities designed to illustrate them.

down one bid and then all bids were revealed simultaneously. The asset was then awarded to the highest bidder at his/her bid price. Each student then turned in his/her bids and an explanation of the bidding strategy, with supporting calculations, to the instructor for grading. Thus, every week, all students had an opportunity to demonstrate their ability to apply the course material to practical examples, whether they ultimately won anything in the auction or not.

Other investment opportunities were introduced as fixed-price options (e.g.- do you wish to buy this for \$1000, yes or no?) rather than through auctions. For

example, in the “municipal bonds revisited” investment, students were given a list of several bonds with a variety of purchase prices, maturity values and maturity dates, and told they could purchase these bonds in any combination, but could not spend more than \$2000. The purpose of the \$2000 restriction was to create an example for which students would be rationing limited capital, regardless of their bank balance at that particular point. Other “fixed-price” investment opportunities introduced later included pirate ships, fishing boats, farms, casinos, and ice cream trucks. Such examples were important to the game because they meant

every student would definitely have the opportunity to make investments- relying on competitive auctions was not a necessity.

The complexity of the required analyses increased throughout the semester, reflecting new topics covered in class. For example, one of the first investment opportunities presented to the class was the theater, with these specifications (taken directly from a class handout):

It costs \$200 (this *includes* routine maintenance and security) to run the theater for each turn it is open for business. It takes a while for a theater to gain popularity. A theater will only bring in \$75 of revenue in its first turn of operation (for a net loss of \$125 that turn.) However, while the cost of running the theater remains constant, the revenues will double each of the next four turns, thus reaching \$1200 in the fifth turn of operation. The revenue will increase to \$1500 in the sixth turn of operation and remain constant at that level for the rest of the time the theater is open.

This investment has a single set of specifications with no uncertainty or risk. Present worth analysis is straightforward, and involves uniform series, geometric gradient series and the concept of equivalence. In a later example, the class had the opportunity to purchase an island, and had several options regarding how to utilize the land if they purchased it (various expenditures that could attract tourists etc.) Consequently they had to apply incremental analysis to determine the best use of the island before deciding on an appropriate bid.

Still later, risk and uncertainty were introduced through several examples. The distinction between risk and uncertainty is that “risk” describes a situation in which multiple outcomes are possible but the probability of each is known. Risk was introduced into the game through examples such as this:

A gold mine produces \$500 of revenue per turn, starting the turn it is purchased, and continuing for an unknown period determined as follows. Each turn, the owner of the gold mine must roll two six-sided dice. If the total of the two dice is seven, the mine yields \$500 that turn but is worthless thereafter. On all other dice rolls, the

mine remains productive the next turn and the dice are rolled again.

Examples like this were used as the first introduction to risk because the rolling of dice was a familiar everyday activity. Later, pirate ships were introduced into the game to illustrate more practical probability distributions. Students could purchase treasure maps that would allow them to “find a buried treasure,” the value of which would be determined randomly, either from a uniform or a normal probability distribution.

“Uncertainty,” by contrast, describes a situation in which multiple outcomes are possible but the probability of each cannot be quantified. This was illustrated in the game through opportunities such as mines and factories. The owner of a mine could make money only by selling raw materials (iron, wood, clay, stone or crude oil) to the owners of factories. Factory owners were permitted to buy these raw materials for \$5/unit in unlimited quantities from the instructor, however, mines were capable of producing up to 300 units/turn of these same materials for \$100 + \$2/unit. Thus, factory owners could buy these same raw materials from student-run mines at prices considerably below \$5 and both parties would benefit. However, because the mines and factories were all auctioned off on the same day, it was impossible to negotiate *exact* terms prior to bidding on a mine or factory— one would not even know who to negotiate with. Further, there was more than one of each type of factory and mine in the game, and the total capacity of all mines was in some cases greater than the total demand for that raw material, and in some cases less than the total demand. These facts introduced elements of competition that made these investment opportunities more realistic and more challenging to analyze.

The simulation also included a 25% income tax rate that only applied to sale of a handful of specific products, which did not become available until well into the simulation. Thus, most examples could be accurately analyzed with a tax-free analysis, but later examples required an understanding of after-tax analysis and depreciation.

Turn Sequence

The class met once a week on Wednesday evening. In general, one turn was

processed each week. On Tuesday, each student turned in a set of instructions, with rationale, describing his/her company’s activity for that turn. This would include production rates in mines and factories, purchases from other students, etc. At the beginning of class, students received from the instructor written summaries of the status of their companies. These gave previous bank balance, expenses, revenues and interest for the turn, new bank balance, and a list of current assets. These summaries were also posted on the course web site. This was important because of the interactive nature of the simulation; students needed to be able to keep track of who owned what.

Any in-class activities, such as auctions, were considered part of the upcoming turn. So, for example, often a student would spend more during a particular auction than he/she had in the bank. That student would have until instructions were due the next Tuesday to borrow money from another student, sell something or otherwise raise the cash. Otherwise his/her bank balance would be negative for that turn and the 15% loan interest rate would apply.

Evaluation of Student Work

The game was integrated into the course as a semester-long project, equivalent to one exam grade. The policy stated at the beginning of the semester was that the student who had the most money on Turn 20 would automatically receive an A, but that this would not necessarily be the only A given. All other students were graded on their demonstrated understanding of the subject matter, regardless of the final dollar amount. The intent of this system was to provide incentive for the students to take the project seriously without creating a system in which students benefited from each other’s mistakes. As hoped, the competition among the students remained spirited but friendly and fair.

In grading the students (excluding the winner), the only criterion was demonstration of an understanding of the subject matter that had been covered so far. For example, when a bond (\$2000 paid on turn 20, with no opportunity for “early withdrawal”) was auctioned off on the first day, students set up the present worth formula but needed to choose an interest rate. Most chose 6-7%, because it was

“better than the bank.” By spending capital in turn 1 on an investment that gives no return until the end of the game, one is in fact not only foregoing bank interest, one is foregoing all the other investment opportunities available later. Consequently, from the perspective of winning the game, 6% is not a particularly good choice. However, the only grading criterion used in this exercise was whether the student had correctly determined present worth for whatever interest rate he/she chose. Later in the game, when minimum attractive rates of return had been covered explicitly, selection of an appropriate interest rate became more of a criterion in grading.

The logistics of assigning a grade are discussed in the “Assessment of Simulation” section.

Rationale for Current Format

An important decision in the creation of the game was whether to use real case studies as examples. It is clear from the preceding descriptions that all specifications for this project were in fact contrived, with no attempt to make the dollar values realistic. Indeed, in most cases, the products themselves are imaginary— among the products manufactured in factories were “widgets,” “gadgets” and “gizzmos.” The rationale for framing the game in this manner had several facets:

- ◆ To ensure that students had no basis for making decisions other than the given specifications and their knowledge of engineering economics. A student might know intuitively which of four real products was the most lucrative, but would have no such basis for “widgets” and “gadgets,” and thus could not make good decisions without learning and applying the course material and doing calculations.
- ◆ The class was open to students from a variety of disciplines and backgrounds. Discipline-specific examples could give some students an unfair advantage in a project that counted for one full test grade.
- ◆ Frivolous examples such as “purchasing a pirate ship to search for buried treasure” gave the class a relaxed and humorous tone, engaged the student’s interest and, ultimately, demanded an understanding of economic principles that was as thorough

as a practical example. Naturally, realism in such activities has advantages too. In teaching operations management, Hartman and Galati⁵ used a business game, adapted from Theusen⁶, in which students ran companies that manufactured CD racks. This exercise, which was also very well received by students, examined many practical issues such as location of facilities that the game described here did not touch on.



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Assessment of Simulation

The game was designed to provide a forum for active learning of the principles of engineering economics. It was highly successful as evidenced by the student response. When asked if the project was “helpful for the understanding of the subject matter” students assigned an average score of 4.83 on a scale of 1-5. Specific comments include:

“I took this class to learn more about economics, and what better way to learn than by actually doing it. I thought the project was an excellent idea. It helped me to apply economics in a way that I had never done before.”

“The simulation was very useful. The teacher tricked us into doing homework by having us work on investment opportunities that were related to the lecture for that week, very clever.”

“This course was great and well taught. The project added excitement to an otherwise dry subject matter.”

“This was the best course I’ve taken. The project is incredible because... if I can do the project I am 100% sure to understand the material.”

In the spring of 2001, the main suggestion for improvement was a request for more specific feedback. Students liked the fact that a single grade was assigned for the semester but wanted feedback on how they were doing more frequently throughout the semester. Consequently, in the spring of 2002, a system was implemented in which each student received a ++, +, +- or 0 for their participation in the project each week, with feedback on the rationale behind the evaluation. The semester grade for each student (except the winner) was based upon these weekly ratings. The spring 2002 class gave posi-

tive feedback on this grading system, and had no substantial suggestions for further improvement.

There were some additional benefits to the project that became evident during the semester. One point was that the project exposed students to some real-world phenomena that are not necessarily covered by a traditional engineering economics course. The best examples were price-fixing and monopolies. The game contained no rules against these practices. The approach was to let them occur naturally and then discuss, within context, the negative consequences they had on the economy as a whole.

Another issue was that students got a taste of how economic realities can be at odds with human instinct. Sunk costs- in other words, money that has already been spent- have no role in an economic analysis. One should analyze the options currently available without being influenced by the specifics of how the current situation was reached. For example, selling an asset for less than the price one paid can be a correct decision, even though doing so may be tantamount to admitting a previous mistake. Students understand this readily enough but during the game found it difficult to follow the practice.

Summary

A game simulating economic decision-making has been devised and integrated with great success into a course on engineering economics. The examples in the game were contrived but were effective in exposing the students to realistic principles. Student response to the game was extremely favorable. It was both an effective and enjoyable tool for helping the students learn traditional engineering economy topics and also dem-

onstrated some phenomena that are probably not covered in most engineering economy courses.

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