Web-Based Simulation Games for the Integration of Engineering and Business Fundamentals

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Abstract

This paper describes a web-based suite of simulation games that have the purpose to enhance the chemical engineering curriculum with business-oriented decisions. Two simulation cases are discussed whose teaching topics include closing material and energy balances, importance of recycle streams, price-volume relationship in a dynamic market, impact of plant scale on capital, operating, and unit costs, and benefits vs. risks of pioneer plants.

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Introduction

Universities do an outstanding job providing a technical education. From undergraduates to postdocs, students learn science and engineering fundamentals, how to read the literature, analyze data, and test hypotheses. However, we believe there is a serious need to improve training on industrial/business fundamentals. Therefore, there is a pressing need to introduce business fundamentals into the engineering curriculum. Producing students who have a stronger appreciation of industrial realities and technical evaluation skills will provide a more competent workforce, as well as more knowledgeable government employees. This is in accord with the recommendations given in a recent NSF-sponsored study led by the AIChE[1].

Case studies and business simulations are proven teaching tools. They immerse students in realistic actual or hypothetical situations that help them improve their problem-solving skills. In addition, cases and simulations are a natural way of using and applying open-ended and practical problems, team projects, and written reports and oral presentations. For instance, Bequette et al.[2] describe the use of case studies during the second half of a process control course. Students work in three-person groups and have to select a case study from a list that covers applications from biomedical to classical chemical processes. The computational tools used include MATLAB and Simulink. Seay and Eden[3] discuss, via case studies, the benefit of including risk assessment methodology and safer process design in the chemical engineering curriculum. They present one example on the design of a storage tank for cyclohexane and another on the recovery system of a solvent (1-propanol).

The use of business simulations is, not surprisingly, more common in the courses offered by business and management departments. For example, Corsi et al.[4] describe the Distributor Game, which is an instance of the Global Supply Chain Game. Briefly, a player (i.e., a group of students) owns a company that distributes four types of computers. The company is located in one of the three regions (U.S., Europe, and Asia). The decisions include global vs. local sourcing and sales, inventory levels to be maintained, and product specialization or differentiation. The challenges faced by the players include heavy competition and the trade-off of having sufficient inventory to satisfy demand while reducing inventory costs. More information about the game can be found at http://www.gscg.org/. In addition, the Online Business Simulations project (http://www.bizsims.edu.au/) contains several resources of business cases and simulations.

Business and economics fundamentals, such as financial analysis, marketing, sourcing, and market dynamics (price elasticity) are inherent to chemical processes. Financial investments in the establishment of sourcing contracts (raw materials), marketing of a finished product, process improvements (operations), environment, health and safety (EH&S), and research and development (strategic decisions) require both business and engineering skills. As an example, Sin and Center[5] describe a Gas Station Game, which is a quantitative pricing game based on Microsoft Excel and aims at illustrating the effect of market forces. Each group of students owns a gas station and has to decide on their business goals and facility sizes. The underground storage capacity is decided in advance and incurs capital and operating costs that will be used to calculate the profitability of a station. A randomized simulation is used to determine the demand in each station based on the stated prices.

This paper describes the *Chemical Business Simulator*, which is a website that consists of a framework for web-based business simulation games. The games enhance the chemical engineering curriculum by requiring the application of both engineering and financial principles to define successful commercial chemical processes. The framework is extendable, i.e., additional cases can be developed and integrated without completely redesigning the website. The simulation games are designed as short-term modules (duration of two or three weeks) that can be used in senior-level undergraduate courses. In the next sections, we will provide more details on the website implementation, as well as describe two available simulation cases: the 2,6-xylenol case, which was applied in the Chem/CBE 505 course (Aspects of Industrial Chemistry and Business Fundamentals) at UW-Madison in the Spring 2016 semester, and the 1,6-hexanediol case.

The Web-Based Suite

The main goal of this effort is to develop simulation cases that enhance the chemical engineering fundamentals (i.e., material and energy balances, reactions, and separations) with elements of business and economics. The cases become part of multiplayer games that dynamically simulate interactions among the decisions made by the participants. The free website can be accessed at http://uwchembussim.che.wisc.edu/.

The authors have partnered with Learning Games Network (LGN), who were involved in the website development process. LGN is an award-winning, not-for-profit organization that both advocates for and develops learning games and assessment tools that benefit learners at every age and around the world. LGN has developed partnerships and technologies that boost the impact of organizations creating, disseminating and researching high-quality educational games and assessment tools. For more information, visit LGN's website at http://learninggamesnetwork.org.

A brief description of basic features as well as the underlying technologies on which the website has been developed is as follows. The website is based on the Python 3.5 programming language, and it uses Flask (a Python-based microframework for web applications) and MySQL relational database. There are three main user accounts: student (only plays simulations), instructor (creates simulations based on existing cases), and administrator (may perform all previous actions, and also design and edit cases). Each case is accompanied by comprehensive documentation files, including Microsoft PowerPoint slides that contain general background information (e.g., process economics concepts) and specific information about the case (e.g., case description, process flowsheets, material and energy balances), as well as a portable document file (PDF) that describes the simulation details (e.g., description and suggestion of values for the initial parameters that must be set by the instructor, equations used in the calculations, tips for providing customized feedback to students, and limitations of the simulation).

We envision the development of new cases that can be used to teach topics such as the following:

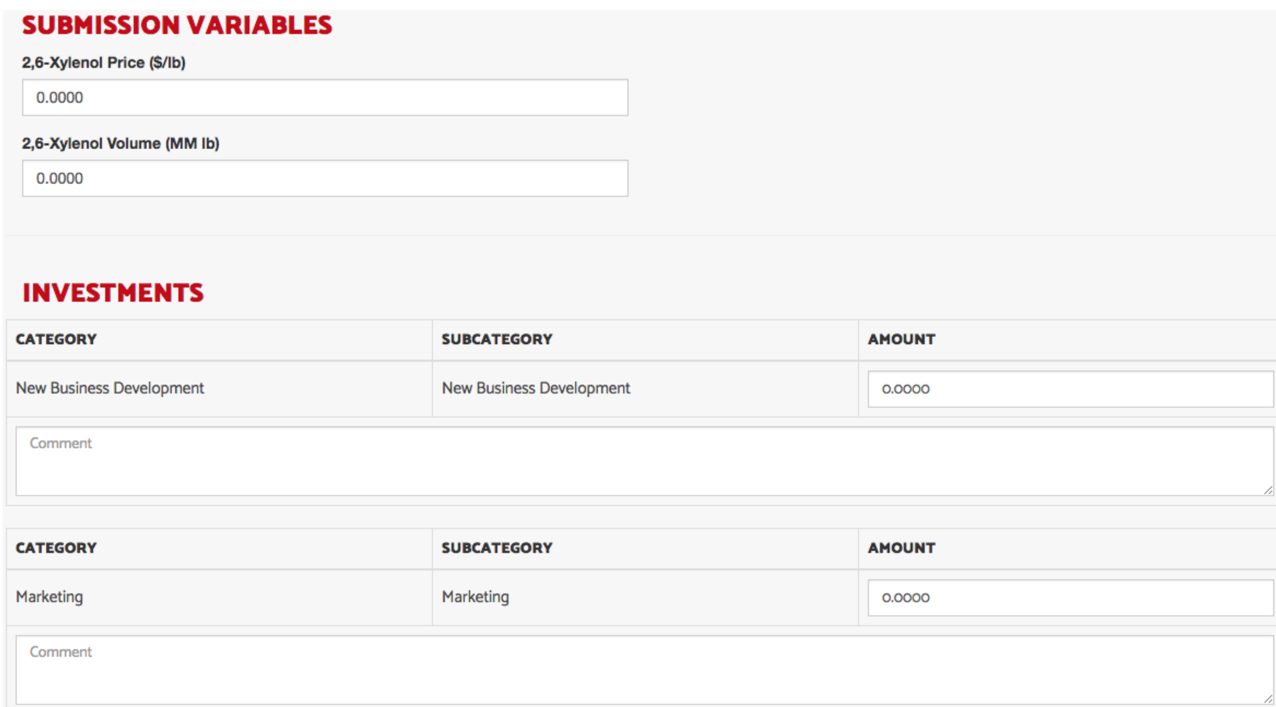
- *Capital Efficiency*: How appropriate sizing of equipment and plants to match expected demand defines commercial success (e.g., net present value, operating rate);
- *Debottlenecking*: The most capital efficient way to add capacity;
- *Catalysis Selectivity*: How selectivity can have important implications on both capital and variable costs;
- *Separations Costs*: The separation costs can be 50% of the capital and energy costs, yet this is often overlooked in commercial assessment.
- *Environment, Health, & Safety*: Consideration of both monetary and non-monetary factors in designing and operating sustainable processes.

Simulation Cases

2,6-Xylenol Case

The main teaching topics of this case study include the importance of closing energy and mass balances, as well as recycle streams, to achieve efficient use of feedstocks. The implementation of the case in the website has a few modifications from the original implementation of the simulation game, which was based on Microsoft Excel spreadsheets. The main modifications include: changing some of the investment categories and their calculation rules, explicit consideration of beginning and ending 2,6-xylenol inventory at each cycle, introduction of a *market dynamics* algorithm, and the use of final cash (not net income) as the objective to be improved. More details are given in the following paragraphs.

The basic settings of this case are as follows. Each group of students takes the role of a technology general manager within a major facility at a chemical company. The students are informed that a sharp decline in sales and price has occurred, which has led to major financial losses in the past two years. Each group is further informed of the budget and brief reports of different programs (R&D, marketing, manufacturing, etc.) in the company in the previous year. The assignment for each group is to prepare a budget statement for their business for the next year with scheduled production volume, selling price of the main product (2,6-xylenol), and investment amounts allocated to each program. The final cash target from the business is at least \$5 MM positive. Along with the budget statement, each group is encouraged to submit comments on the expected outcome of the respective investments (see Figure 1). Additional background information is also provided, such as reactor design and operating conditions, number of stages and feed stage of the distillation columns, process chemistry, and the mass balance of select streams. The process flowsheet is also given and shown on Figure 2.



SUBMISSION VARIABLES

2,6-Xylenol Price ($/lb)

0.0000

2,6-Xylenol Volume (MM lb)

0.0000

INVESTMENTS

CATEGORY	SUBCATEGORY	AMOUNT
New Business Development	New Business Development	0.0000
Comment		

CATEGORY	SUBCATEGORY	AMOUNT
Marketing	Marketing	0.0000
Comment		

Figure 1: Partial submission form showing the inputs required by students for the 2,6-xylenol case.

When a group makes enough investments (i.e., beyond a predetermined threshold value) in key categories (e.g., manufacturing, marketing, and new business development), certain

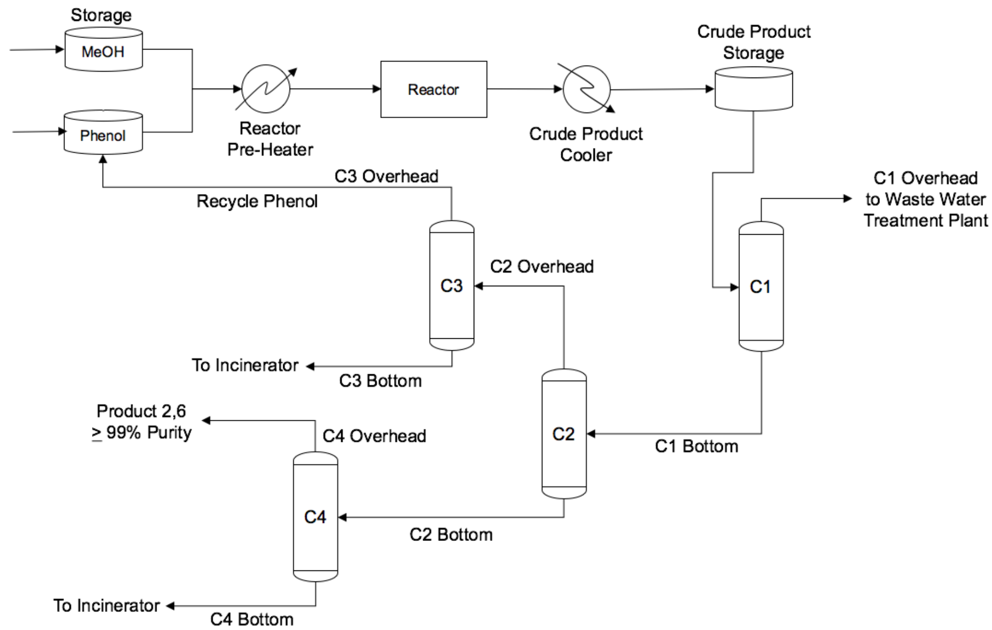


Figure 2: Process flowsheet for the 2,6-xylenol case as it is given to students at the beginning of the simulation.

process improvements are activated. These improvements lead to changes in the original process flowsheet. A few examples include: some of the distillation columns may be operated differently in order in order to change the product distribution in the bottom and top streams, or heat exchangers may be installed to improve heat integration, or an improved catalyst that results in higher conversion and selectivity for the desired product (2,6-xylenol). In this new implementation of the simulation game, rigorous Aspen Plus® steady-state simulations were developed for the original process flowsheet and all combinations of the improved flowsheets. However, incorporating these simulations into a website poses significant technical challenges and potentially licensing issues. Therefore, we performed sensitivity analyses for all flowsheets and used the generated input-output data to develop reduced-order models [6] for each flowsheet. These models are algebraic in nature and can be easily incorporated in a scalable and portable web-based framework.

An interesting aspect of the simulation game is that it considers price-volume relationships and market dynamics, which means that the decisions of a player affect the decisions of others (i.e., the players do not run companies in isolation in a market). For example, by pricing 2,6-xylenol too high, a group may lose market share as customers will prefer to buy the same product from a producer that is offering a lower price. However, pricing too low may significantly reduce the revenue from sales. Therefore, groups have to find a balance between selling price and scheduled production, in addition to managing inventory.

1,6-Hexanediol Case

The main teaching topics of the 1,6-hexanediol (1,6-HDO) case include: the impact of plant scale on operating, capital, and unit costs by using cash flow analysis (time value of money), risks vs. benefits of building a chemical plant based on new technology (pioneer plant), and price-volume relationship in a dynamic market setting.

1,6-HDO is an intermediate-volume, but high-value commodity chemical that is used in the production of polyurethanes, coatings, and acrylates[7]. Traditionally, benzene is a basic feedstock for the production of 1,6-HDO. Research on alternative biological routes is under way, but there are currently no commercial-scale chemical plants that implement these new technologies. Even if an alternative route appears to be more technically and economically favorable than a well-established technology, the variability between estimated and actual costs can be significant for pioneer plants that implement such novel technologies. In addition, it is expect that there is a cost growth associated with building first-of-a-kind plants for which little to no design and operations experience has been gained[8].

In this simulation case, each group of students owns a chemical plant that produces 1,6-HDO via the traditional route. A key and one-time decision that students have to make by the end of the first cycle is whether to expand capacity (10% stretch based on the existing plant), or build a new plant at different and predetermined scales (50%, 100%, or 150% of the current plant capacity) using either the traditional or the alternative biological route (see Figure 3). In subsequent cycles, students have to submit selling price and scheduled production volume of 1,6-HDO. The simulator performs cash flow calculations based on the process economics analysis of rigorous process flowsheet models. At the end of each cycle, students are presented with a statement of cash flows and a graph showing the evolution of cash throughout the simulated years. The simulator quantitatively considers the risks and benefits of implementing a new technology as mentioned in the previous paragraph. A market dynamics algorithm is also applied, which makes the simulation more realistic and promotes interactions between the groups' decisions.

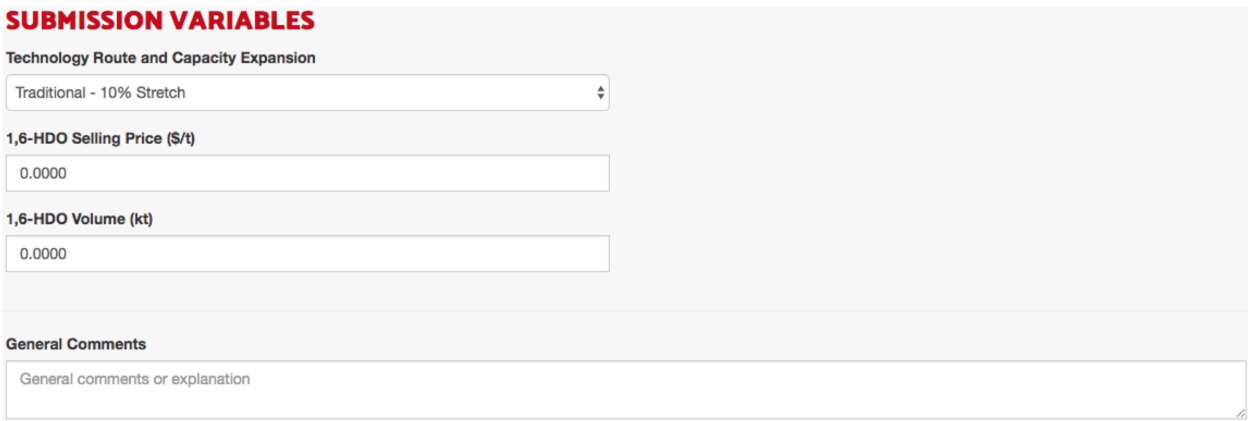


Figure 3: Submission form showing the inputs required by students in Cycle 1 for the 1,6-hexanediol case.

Discussions

The 2,6-xylenol case was introduced in class using the slides available in the website, and the students were deliberately assigned to groups by the instructors (the website gives the instructor the option to allow or forbid students to create their own groups). In creating the groups, the objective was to make them as diverse as possible, i.e., by assigning undergraduate and graduate, chemistry and chemical engineering students to the same group. The simulation activity was executed at the end of the semester and lasted for two weeks.

Figure 4 shows some of the highlights of the text inputs by students justifying their budget investments in some of the categories as illustrated in Figure 1. The comments by students clearly show how they rationalize their engineering and business decisions, and they can be useful for the instructor to gauge the students' understanding of the problem and provide feedback on their performance. After concluding the simulation, the students were surveyed and asked to provide feedback on the simulation activity. Samples of negative and positive feedback comments are shown in Figure 5. The majority of the negative comments were related to the limited available information and time constraints. Since the execution of this simulation, the material containing background information has been expanded and clarifications have been made; however, it is advised to take caution in providing hints to students in order to avoid inadvertently disclosing the answers to the problem. It may also be important to consider executing the simulation earlier in the semester and probably for a longer duration (e.g., three weeks), thus avoiding the period of final examinations. However, we note that it is also an important teaching lesson to intentionally have ambiguous information and limited time in the simulation to mimic real-life situations. It is expected that some students struggle with open-ended problems, while others appreciate this feature in the simulation. The positive feedback comments provide evidence that students valued the real-life situation created by the simulation, as well as the market dynamics feature, and the fact that they had to use their technical skills with business fundamentals to tackle problems.

*"The 2 MM$ for **process control** and support has the same motivation as the money allocated for **improvement of the measurement system**. This money will be used to continue the work on the reactor model that was recently terminated. (...) Again, work to maximize reactor selectivity is imperative to improve yield and production of 2,6-xylenol, which is the only product of this process."*

*"We allocated the most funding to **R&D** this year. Last year, promising results were seen on the pilot scale, so we will continue to fund this area in hopes of a **new catalyst** coming through within the next two years."*

*"1 MM$ in **sourcing** ensures our feedstock cost price will not rise as well as possibly **bring our feedstock costs down**, and increase profit margin. We hope to maintain our current feedstock costs as these were our greatest cost savings area."*

*"Now that we have projected in cycle 2 to be profitable, we can gear our endeavors towards **environmental compliance**. In the earlier years, we were focused on quick turnarounds in order to get the business running. Now that we have an operational plant, 1 MM$ in environmental compliance will lead to becoming a **better company**."*

Figure 4: Highlights of text inputs by students justifying their investments in key categories in a simulation based on the 2,6-xylenol case.

"It probably would have been more fun had there been **more time to work on it**."

"The simulation was good, but it really suffered from how **little input** everyone had."

"The simulation **should be held earlier in the semester** with notice given as to when it will occur. (...) I could have budgeted time better if notice was given a week in advance as to when it was to occur."

"**More information** regarding the problem should be given."

"**More time** in between simulations and more time in general. Being a graduating senior with several group projects at the end of the semester made it difficult to find a good time for such a large group to meet, especially across different majors."

"This was a great simulation. I liked how it left many ends open. This really helped facilitate the **discussions between groups** and analyze the aspects of the simulation in many different ways. It was definitely not clear what to invest in, so it forced us to **rationalize our decisions**. It gave a good feel as to how tough these decisions can actually be with **limited information**."

"(...) As far as the business topics go, **this simulation really hit on market analysis**, and forced us to think about what other groups/companies were going to do. **Pricing the product was key** to be successful in response to the market analysis."

"**It brought together engineering and business**. It also represented a **real life situation** in which you **do not know what other companies in the market will do**."

Figure 5: Samples of negative (left) and positive (right) student feedback comments obtained after concluding a simulation based on the 2,6-xylenol case.

Conclusions

This paper introduces a free website that is a repository of cases, which constitute of simulations that integrate engineering and business decisions. Each case is designed as a game in which students work in groups to submit, for example, selling price, scheduled production volume, and budget proposals containing investment amounts in different categories. The investments may activate certain improvements in the chemical process, and the pricing decisions by a group affect the decisions of others through the use of a market dynamics algorithm.

The website has been developed to be extendable, which means that additional cases that will be and are currently being developed can easily be added. Also, several ideas implemented in the 2,6-xylenol and 1,6-hexanediol cases (e.g., cash flows, inventory management, and market dynamics) can be reused in other cases to be developed. New cases may be conceptualized by any person in academia or industry, and then added to the list of cases by the website administrator. We highly encourage professionals to contribute with new cases, especially influenced by their own experiences, that teach valuable lessons about how business decisions affect the profitability of a chemical process.

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