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# Online and Interactive Simulations to Teach Manufacturing and Supply Chain

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## Abstract

The outbreak of 2019 Coronavirus Disease (COVID-19) has forced schools and universities around the world to adopt online learning. However, many educators are facing challenges because they do not have prior experience with online teaching and the transition happened rapidly. One effective way to keep students engaged and improve their learning is by using online simulation games. Simulation games provide opportunities for feedback and learning and can promote interdisciplinary and collaborative working styles. This research develops internet-based multi-player interactive simulation games to teach manufacturing and supply chain concepts. The players in the supply-chain games include a customer, a manufacturer, an assembler, and a supplier. The simulation games are structured into three different parts: the backend server that handles the game logic, the client server that takes user input, and the database which stores the input information. The simulation involves producing car toys that satisfy customer requirements. A group of high school and community college educators tested the simulation games and provided feedback for improvement. The simulations were then deployed in the practice of high school and undergraduate classrooms. Feedback from teachers and students indicates that online simulations can improve effectiveness of teaching and learning.

## Keywords
Manufacturing, Supply Chain, Simulation, Gaming

## 1. Background

Today's manufacturing systems and business environments are very complex and dynamic. To teach these complex systems to high school and undergraduate students, simulation tools can be more effective and offer many advantages compared to traditional teaching methods. Simulation modeling and games allow for the demonstration of abstract concepts and enable the interaction between users and environment, thereby providing users with feedback to improve their knowledge and skills. Many advances have been made that enable the experimentation and analysis of real-world phenomena using simulation and emulation environments [1]. The development of web-based user interfaces for these simulation environments can support problem-based Science, Technology, Engineering, and Mathematics (STEM) education [2]. Such web-based simulation tools can be very helpful these days as schools and universities around the world are forced to adopt online learning because of the 2019 Coronavirus Disease (COVID-19) epidemic. First applied in training in the military and aeronautics industry, simulation games are now used in different applications including worker training [3], laboratory research [4], and pedagogy [5]. A growing body of literature describes new simulation games and discusses the effectiveness of using simulations to improve learning [6-7]. Prior works showed that simulation games deliver learning outcomes for engineering education but can have drawbacks to their use that need to account for such as high cost of development and the need for expert facilitators for running game sessions [8]. A study presented a cloud simulation platform that provides computing resources and services for hybrid simulation of virtual manufacturing systems [9]. The platform embeds all the necessary features, easing programming of rich applications and enabling the creation of an environment where complex process control algorithms can be developed. A new simulation game for operations management education was developed by Pasin and Giroux [5]. Results from the study showed that although simple decision-making skills can be acquired with traditional teaching methods, simulation games are more effective when students have to develop decision-making abilities for managing complex and dynamic situations. Other studies also Discrete Event Simulation (DES) to educate students about manufacturing systems design [10]. A summary of the simulation uses in education, especially manufacturing, is shown in Table 1. In this research, we develop web-based simulation games to transform abstract concepts in manufacturing and supply chain into interactive visual contents. This allows students to understand the relationship between different system components and be able to make effective decisions to optimize the system performance. Moreover, the simulation games offer a real-time tracking of students' progress on system parameters such as cost, time, and throughput and provide them with regular feedback to improve their skills. The simulation games were developed by a group of undergraduate students under the supervision of industrial engineering professors and feedback from high school teachers and community college faculty.

Table 1: A summary of simulation uses in education

| Study | Simulation Type | Application Area | Research Focus | Research Finding |
|---|---|---|---|---|
| [11] | Hands-on | Lean Manufacturing | Use hands-on simulation experiments to teach lean manufacturing concepts | Simulation is effective for teaching lean concepts |
| [12] | Web-based | Marketing | Compare simulation games with lecture-centered approach | Simulation game is superior to a lecture-centered approach |
| [13] | Web-based | Medical imaging | Teach students or other trainees who plan to work in medical imaging field. | Model can support online medical imaging education |
| [10] | Computer simulation | Metal Industry | Teach manufacturing systems using computer simulation. | Students improved their technical and non-technical skills |
| [14] | Virtual system | Manufacturing | Develop architecture of virtual manufacturing systems and virtual programmable controller | Possible use in education and in design, planning and control of advanced manufacturing systems |
| [15] | Virtual system | Manufacturing | Develop engineering education environment of a flexible manufacturing system (FMS) | Students have a comprehensive understanding of a typical FMS |
| [16] | Virtual system | Automotive Manufacturing | Determine impact of gaming experience on learning process of a manufacturing operation using virtual simulation | Gaming experience influences positively on training completion time using the virtual system |
| [17] | Web-based | Manufacturing | Impact of an ERP simulation game on online learning | Students develop more positive attitudes toward SAP and gain increased knowledge of ERP |
| This study | Web-based | Manufacturing | Study effectiveness of online manufacturing simulation on student learning | Online simulations can improve teaching & effectiveness of learning |

## 2. Methodology

This research develops a computer simulation game of manufacturing and supply chain, then compares it with a physical system that utilizes plastic bricks. The server is able to handle up to 1000 different games simultaneously and can be easily upgraded to handle more. The basic structure of the simulation game is shown in Figure 1 and the homepage of the application is shown in Figure 2.

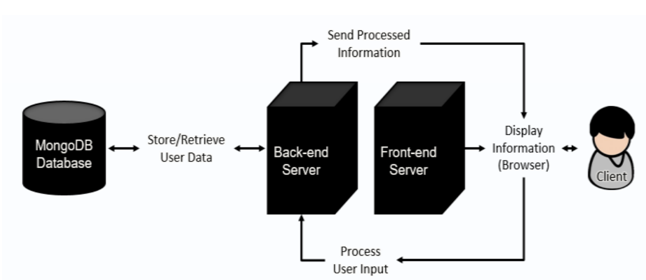


**Figure 1:** The structure of the simulation game

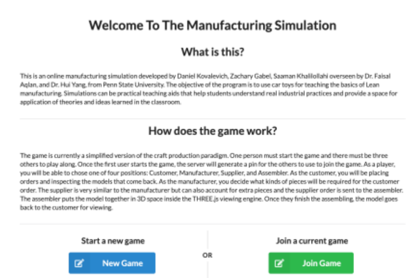


**Figure 2:** The homepage of the simulation game

The simulation game is available at http://mfgsim.herokuapp.com. When the players enter the start page of the website, they will first read instructions of the manufacturing process and a brief explanation of the game itself. The players are able to then choose whether they wish to join a game that is currently in progress or start a new game. When a player starts a new game, they have the ability to choose a type of production paradigm (e.g., craft production, mass production, etc.). The server will generate a unique pin, which is used to invite other players to join the game, and the player can choose between acting as a customer, a manufacturer, a supplier, or an assembler. A player must wait until all the other players join the game (see Figures 3). A sample bill of material (BOM) for a given customer order is shown in Figure 4.

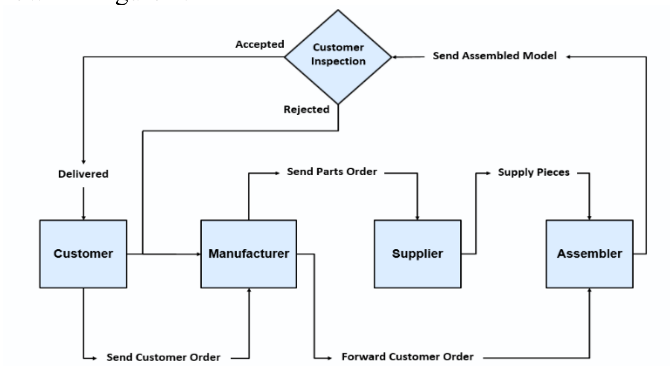


**Figure 3:** Basic structure of a simulation scenario

| Item Type | Size | Weight (per item) (g) | Price (per item) ($) | Quantity | Total Weight (g) | Total Price ($) |
|---|---|---|---|---|---|---|
| Rim | 2 | 0.25 | 0.20 | 4 | 0.50 | 0.80 |
| Tire | 2 | 0.65 | 0.15 | 4 | 1.30 | 0.60 |
| Windshield | 2x4 | 2.50 | 0.38 | 1 | 2.50 | 0.38 |
| Wheel | One Size | 0.60 | 0.29 | 1 | 0.60 | 0.29 |
| Driver | One Size | 3.47 | 1.00 | 1 | 6.52 | 1.00 |
| Axle | 2x2x1 Pin | 0.95 | 0.18 | 4 | 3.80 | 0.72 |
| Plate | 2x8 | 2.25 | 0.25 | 1 | 2.80 | 0.25 |
| | | | | Total | 16.22 | 4.04 |

**Figure 4:** Sample bill of material for an order

There are seven main webpages in the system: the start page, the join-game page, the order viewer, and one page per player (customer, manufacturer, supplier, and assembler). The start page displays an overview of the simulation and allows the user to start or join a game. Once all players have joined a game, each player will be directed to the page that matches the role that he or she chose. The customer page displays a set of pre-defined order specifications and also allows the user to create a custom order using an uploaded image and notes. The page displays information about the orders placed, including completed orders. The manufacturer page displays all available pieces and colors that can be ordered from the supplier to satisfy customer orders as well as price and weight information for each piece. The supplier page also allows the selection of pieces and colors, and then fulfill manufacturer orders. The builder or assembler page includes a 3D environment developed using three.js, a JavaScript 3D library, in which players can build the car toys. Sample snapshots from the simulation game are shown in Figures 5-8.

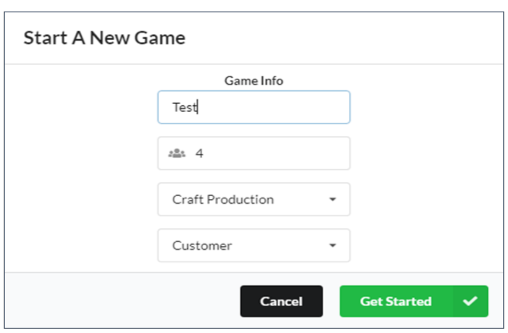


**Figure 5:** Starting a new game

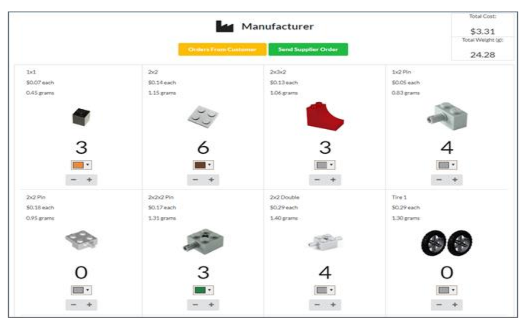


**Figure 6:** Manufacturer page

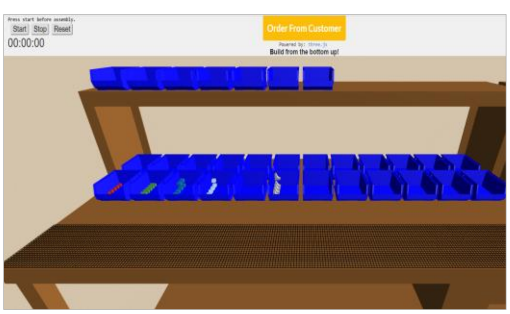


**Figure 7:** Assembly station

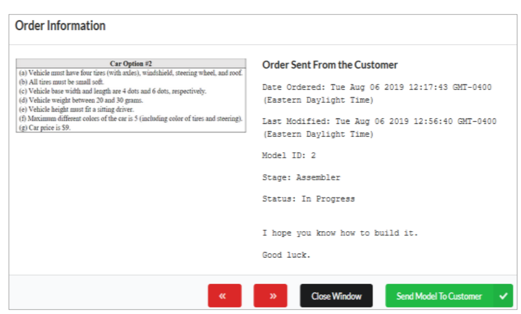


**Figure 8:** Sample customer order

## 3. Experimental Results and Discussion

The simulations were tested by groups of high school and community college educators, undergraduate students, and graduate students (online simulation only). The first three participant groups performed physical simulation activities where they were asked to produce car toys using plastic bricks. Then they used the online simulation platform to produce similar car toys. Teams a, b, and c in Figure 9 produced car toys using the physical and online simulations whereas team d only used online simulation. The participants can choose a pre-specified customer order or generate the order randomly. Each customer order includes specifications for car size, weight, price, and colors. In Figure 9, the car toys produced by Teams a and c met the customer requirements whereas Team b and one member of Team d were not able to meet the exact customer requirements because they did not include roofs for the car toys. Those car toys are returned to the builder for repair.

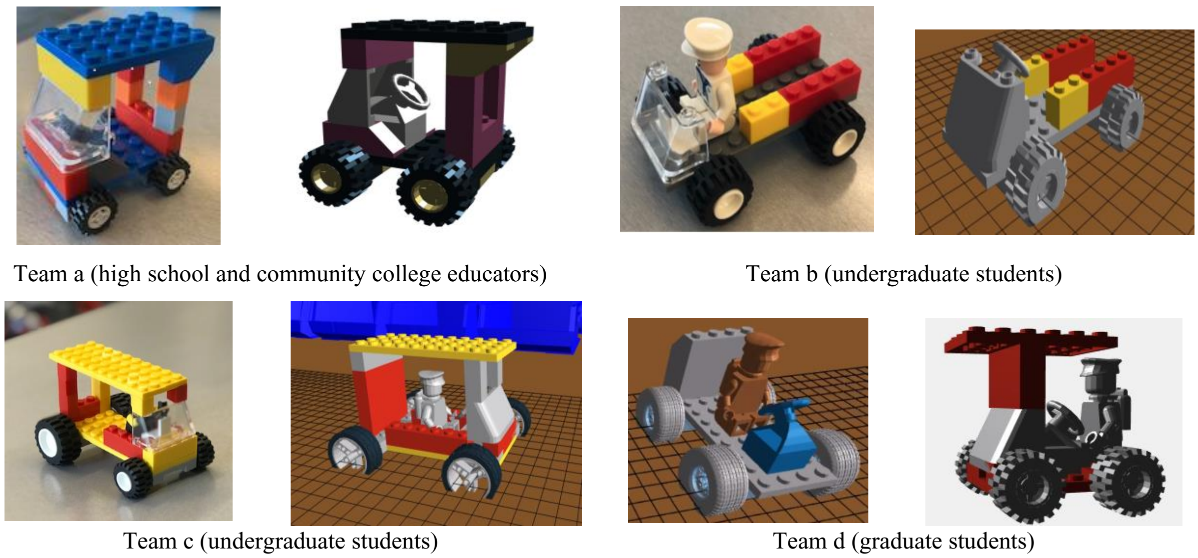


**Figure 9:** Sample car toys produced by the participants

After testing the simulations, a group of 13 high school and community college educators were asked to provide feedback for improving the online simulations. A sample survey of five questions is shown in Table 2. As indicated in Figure 10, survey results show that the educators were able to learn the basics of manufacturing systems by participating in the simulations. Based on the specific simulation scenario they participated in, their answers to the first three questions were correct. Answers to questions 4 and 5 indicate that the build station was the bottleneck and the person who handles the assembly of the car toy needs to be well trained. Answer to question 5 indicates that the participation in the physical simulation may help the participants play the online game effectively to some extent.

**Table 2:** Sample survey questions for evaluating the simulation games

| Question | Question | Answer |
|---|---|---|
| Q1 | Did the style of production focus on quality or quantity? | (Quality) 5 4 3 2 1 (Quantity) |
| Q2 | When was the customer most involved in the process? | (End) 5 4 3 2 1 (Beginning) |
| Q3 | The assembler workforce in the simulation is … | (Skilled) 5 4 3 2 1 (Unskilled) |
| Q4 | Based on your role as the assembler, please reflect on this statement. "The output of product would increase as I became a better builder" … | (Agree) 5 4 3 2 1 (Disagree) |
| Q5 | Did participating in physical simulation help you effectively play this game? | (Agree) 5 4 3 2 1 (Disagree) |

NASA Task Load Index (TLX) was used to survey undergraduate and graduate student's perception of task demands [18]. Undergraduate students performed both physical and online simulations whereas graduate (master) students only performed online simulations. The NASA-TLX uses six questions to assess mental demand, physical demand, temporal demand, performance, effort, and frustration. Each question has a rating from 1 to 10, where 1 represents the lowest task demand, and 10 represents the highest, with the exception of the performance question, where 1 indicates the highest, and 10 indicates the lowest [19]. Table 3 shows the NASA-TLX questionnaire. The results of the NASA TLX form an undergraduate course (physical simulation and online simulation 1; n=23, 39% women) and a graduate course (online simulation 2; n=13, 23% women) are shown in Figure 11. The figure shows the TLX results for both physical and online simulation and it can be noted that the online simulation requires less mental, physical, and temporal demands as well as less effort. The performance of the teams was higher for the physical simulation which is reflected by the students' rating to the "performance" item of the TLX survey. Improvements are being made to the online simulation to make the assembly process of the car toys easier. The frustration level was higher for the online simulation when compared to the physical simulation by undergraduate students but was lower when graduate students performed the online simulation alone.

**Table 3:** NASA TLX items and their description

| Item | Scale | Description |
|---|---|---|
| Mental demand | 1-10 (Low-High) | How mentally demanding was the task? |
| Physical demand | 1-10 (Low-High) | How physically demanding was the task? |
| Temporal demand | 1-10 (Low-High) | How hurried or rushed was the pace of the task? |
| Performance | 1-10 (Perfect-Failure) | How successful were you in accomplishing the task? |
| Effort | 1-10 (Low-High) | How hard did you have to work to accomplish your level of performance? |
| Frustration level | 1-10 (Low-High) | How insecure, discouraged, irritated, stressed, and annoyed were you? |

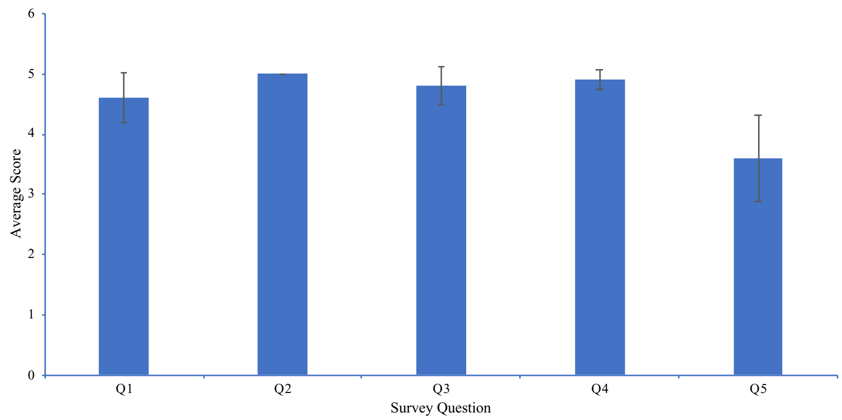


**Figure 10:** Survey results for high school and community college educators

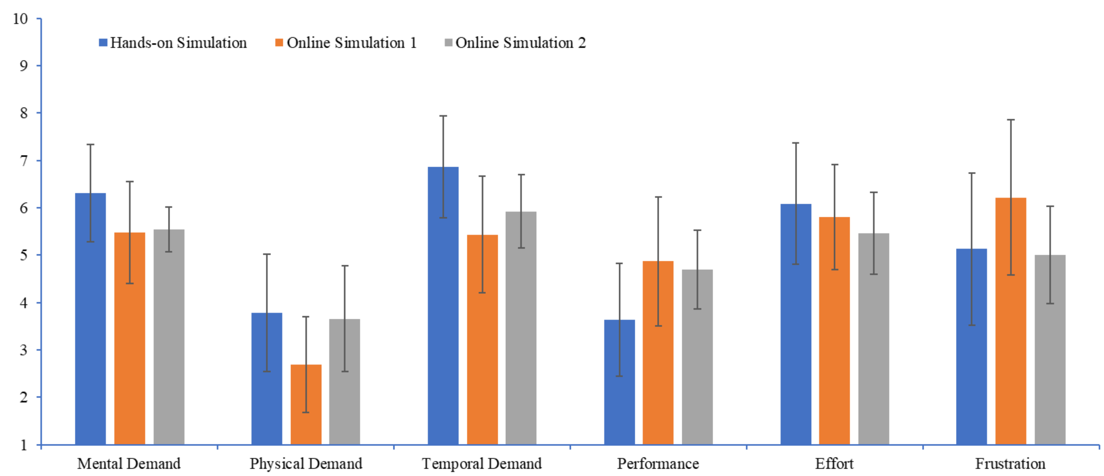


**Figure 11:** NASA TLX results for undergraduate student participants

The graduate students reported that the online simulation helped them understand the concepts of manufacturing and supply chains. Sample comments: (1) "This was a great to understand craft production, and the mental constraints/frustrations associated with making the product flow properly through the assembly process", (2) "The simulation was very intriguing. Yes, it is a little clunky but for being a web-based assembly game, overall it was well executed. Once you figure out the controls and get your first couple pieces on, it is simple and fun. This was probably one of the more enjoyable activities for the weekend", (3) "This was a nice simulation program to show how each of the supply chain components are affected and are intertwined to be able to build an object and can also show how assembly time and design can affect the overall price", (4) "This was a good demonstration to show the disconnect throughout the supply chain. With the manufacturer, supplier and assembler being in different locations, it showed how difficult it was to communicate throughout".

## 4. Conclusions and Future Work

This paper presented a web-based simulation game for teaching the concepts of manufacturing and supply chain. The simulation game was implemented in the practice of high school and community college educators, high school students, and undergraduate students. Preliminary results showed that online simulation improves the effectiveness of teaching and learning. In future work, we will continue to enhance the simulation by reducing the level of frustration that can be caused by technical limitations of the hardware. For example, a touch screen option for the assembly process of car toys will be added. Simulation scenarios that represent different types of manufacturing paradigms (e.g., lean manufacturing and Industry 4.0) will be considered.

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