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Simulation of Production and Inventory Control using the Computer Game Factorio

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Abstract

This paper describes the development and testing of an online lesson on the subject of inventory and production interactions, including visual simulations of the mathematical cause and effect between important production metrics. The mathematics behind how items flow through a factory is important for industrial engineers as they are often charged with designing systems to maximize this flow. However, it's often difficult for students to imagine the interactions between the important metrics and how the entire system operates. The computer game Factorio, was used as a simulation tool to help students visualize and measure the interactions and verify optimization algorithms that were reviewed as part of the lesson plan. The lesson plan was developed for use as stand-alone online modules for students to work through on their own.

Introduction

It is often difficult for students to see how the theory that they are presented in classes applies to the situations they will encounter in their careers. Research has shown that perceived abstractness of theoretical concepts and separation of those concepts and the students' experiences can be a hindrance to learning. [1] Experiential learning, project-based learning, and service learning are all teaching methods used to help students learn theory by connected it to real-world situations in which the theory can be used to solve problems. This paper describes an effort to use game-based learning to design lessons that would enhance learning of complex problem solving and reduce the perceived abstractness of theory presented in a Production and Inventory Control course for juniors in an Industrial Engineering program.

Computer Simulation and Game-Based Learning

Computer simulation and game-based learning were used in the design of two lessons in a Production and Inventory Control course in order to help students visualize theoretical concepts. Computer simulations are programs that represent a real-life system or occurrence. Simulations are especially useful in teaching situations which cannot be brought to a lab because of the expense or the space requirements. Time can also be controlled in a simulation so that conditions that would take hours, days, or even weeks to observe can be viewed in only seconds. The biggest advantage of using simulation in the classroom is that they allow the user to control variables, test hypotheses, and experiment in a way that could not be achieved otherwise. [2] Simulations have also shown to aid students in learning how to solve complex problems. Research into how learners approach problems

shows that expert problem-solvers begin with a qualitative analysis of the problem before moving into the quantitative computations, while novices tend to jump right into quantitative equations without thinking much about the problem as a whole. [3] Research on advancing problem-solving skills shows that tools that help students visualize a physical situation help novice problem-solvers to see the importance of first thinking qualitatively about a system as a whole. [4]

Game-based learning (GBL) is the term used for actual games being used in the classroom to enhance learning and teaching and to satisfy learning objectives. [5] While GBL can be used with any type of game, including paper-and-pencil games, board games, and video games, this project is focused on the use of video games as a learning tool.. GBL incorporates six key learning function: they activate prior learning; they teach relationships between knowledge and context; they provide feedback and assessment of in-game actions; they encourage application of knowledge, they accommodate experiential learning; they foster the sharing of knowledge. [6] A large sample size, quantitative study on the effects of GBL on enjoyment, engagement, and learning in higher education found that games in the classroom increased reported enjoyment levels, especially in subjects where students reported the greatest anxiety about learning. In the study, the increase in enjoyment correlated positively with improvements in high-order thinking and deep learning. [7]

Project Motivation

The motivation for this project was two-fold. One goal was to increase students understanding of how materials flow through a factory by helping them connect the mathematical theorems they learn in class with the knowledge of what this all looks like in actuality. Specifically, a class learning objective was for students to explain and predict the interactions of work in process inventory (WIP), throughput, and cycle time using Little's Law. Because there is no factory lab for the students to visit, we needed to find another method to help students make this connection between an equation and actual interactions. The Factorio game, looks somewhat realistic, but more importantly it behaves very realistically in the flow of parts through an automated factory setting. Students could calculate the expected cycle time using Little's Law and then observe the actual cycle time by watching the line run in Factorio.

The second motivation was to determine if watching others go through a scenario using a video game could be both informative and enjoyable. Watching other people play video games is not a new idea. Twitch.com is a live streaming service that was introduced in 2011 focusing on video game streaming. In 2020 it had 15 million daily active user watching broadcasters stream themselves playing video games. [8] The site has also shown success in using video games as a teaching tool for novice instructors to reach a wide audience of learners who can interact with each other in real time. [9] To date, research into the efficacy of using Twitch as a teaching tool has been in tutorials on video games themselves or on computer programming instruction. There is no known research on the use of Twitch video game streaming to teach other types of curriculum.

This project was an attempt of a proof-of-concept of students' acceptance of viewing a video of another person "playing" a video game to strengthen the students' understanding of theoretical concepts.

Lesson Creation

The online lesson was developed for IE 4303, Introduction to Production and Inventory Control. This course, which is required for all undergraduate Industrial Engineering students, is taught each fall semester. The course teaches the mathematical theory of the operation of real-world production systems. It is a good choice for evaluating the use of a simulation tool, because while the content of the class is very applicable to real systems, it is not possible to for students to see the actual production systems working. This simulation will allow the first-semester junior level students to envision how the theoretical mathematical models they are learning apply to production systems, thereby allowing them to qualitatively view the system prior to making quantitative decisions, as expert problem-solvers have been shown to do. [4]

The developed lesson was designed to supplement existing content in the course. Therefore, no additional in-class time was needed to be devoted to the topics. The lesson was presented in a self-contained online Canvas module, so the faculty member only needed to make students aware of the lesson and make the assignment.

Lesson Content

Little's Law is a theorem studied by students in many different disciplines. It defines the relationship between the throughput, work in process, and cycle time of any system. The theorem is interesting because it is applicable to any number of systems with a queue. An assembly line of parts, a line of customers at a bank, a backlog of planes in a holding pattern over an airport, all follow the mathematics of Little's Law. It's often difficult for students to imagine the interactions between these metrics and how the entire system operates. This theorem was chosen as the focus of the developed lesson for these reasons.

Factorio

The commercially available computer game Factorio [10] was used to demonstrate production line design, inventory control, and theory of constraints concepts. Factorio is a manufacturing simulation game developed by Wube Software. The game is free-to-play and can also be downloaded completely free in single-player mode. The game allows users to collect resources, manufacture items, research advanced technologies, and design automated systems. There is a story mode where players are led though the gameplay with scenarios introduced and a winning condition given. There is also a sandbox mode available, for players to play however they want without having to meet any given goals or playing through any build scenarios. A small, two-machine assembly line in the sandbox mode was created to demonstrate production and inventory control metrics in the videos for this project. The developers of Factorio have allowed users to create modifications to the way the game runs. This process, known as modding, not only allows, but encourages modification of the game to work in ways not originally intended by the designer. A mod was used to eliminate some notifications that would be needlessly distracting . A computer script was also written to change some of the default manufacturing times of the machines in the assembly lines. The default manufacturing times were very quick and needed to be slowed down so that the viewers of the videos could more easily visualize the processes that were occurring.

Open Broadcaster Software

Open Broadcaster Software (OBS) was used to record the videos and overlay information onto the video screen. OBS is a free and open source software for video recording. [11] With Factorio running, OBS was used to capture the Factorio window and record both the Factorio game sounds as well as voice over the game for required explanations. For one video, an additional overlay of a timer was used to introduce the concept of throughput. While the Factorio assembly line was running the time overlay displayed elapsed time, so that the number of completed products per minute could be calculated. The resulting rendered video was then uploaded to Canvas Studio for more text overlays.

Canvas Studio

The video created in OBS was then uploaded to Canvas, the learning management system used at the authors' institution. Canvas Studio was then used to add text overlays to the video. The text overlays reinforced terminology given in the voice explanations of the videos. When a new definition was mentioned, such as Raw Material Inventory (RMI) inventory, the term was displayed on the screen indicating the places in the video where the viewer could see RMI occurring was also added. These text overlays were used to make clear the connection between the terminology being introduced in the voice explanations and the visualization of the actual process, metric, or items being described in Factorio. Figure 1 shows a screenshot of one video with the described text overlays.

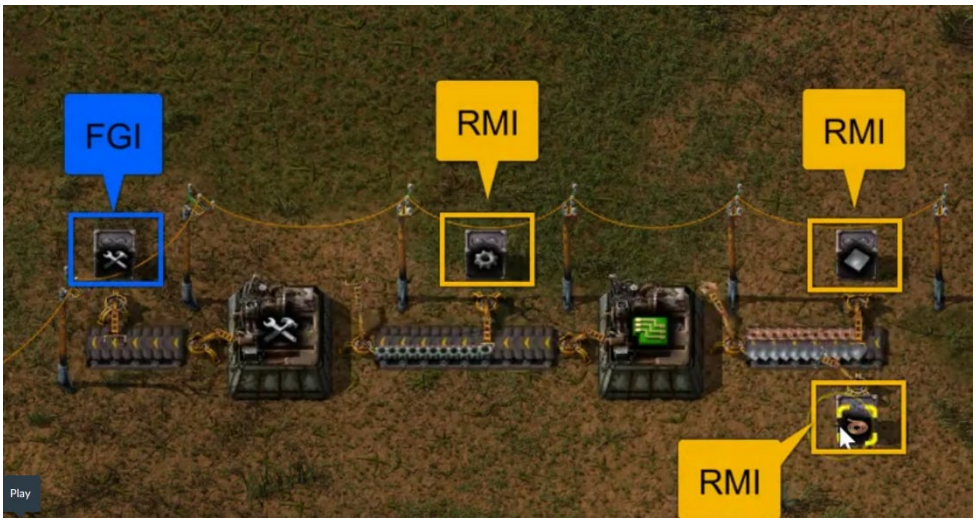

Figure 1. Screen Capture of Text Overlays

Assignment to Students

Students were assigned the developed lesson as one of many "mini-projects" that were each part of student's final grade. In this mini-project students were asked to read a Canvas page that presented in text some terms and metric definitions that would be described again in the video. The students were invited to complete an online exercise where they matched terms and definitions to test their understanding of the terms. This exercise was not graded or required. Students were then asked to read a description of a repair pack manufacturing process. They were also presented with a bill of materials for the production process.

Students then watched the first video, titled Factory Flow Definitions, which is 4:37 long. It describes

and shows of examples of factory flow definitions that had previously been presented in the context of the repair pack manufacturing process to which they had been introduced. The second video, titled Factory Flow Metrics is 9:05 long, and was developed to help students visualize the manufacturing metrics that had previously been defined for them. In this second video the assembly line runs and important metrics, like throughput and cycle time are demonstrated. Both videos are publicly available on YouTube and are linked in this reference. [12]

Finally, students were asked to reflect on this online lesson once they completed it. The reflection questions are presented in Table 1.

Question #	Question Text
1	How much did the videos help to improve your understanding of factory flows in general, and Little's law specifically? In particular:
1a	Which aspects of the videos were most helpful in improving your understanding? Please explain in detail.
1b	Which aspects of the videos were least helpful? Why? What could be done to improve these aspects?
2	In class, we used an Arena simulation model to represent the flow of materials on a simple assembly line and then capture relevant performance metrics. Which was more helpful to your understanding of factory flow concepts: the simulation model, or the video game? Why?
3	What do you think about the potential for using video games as a way of exploring Industrial Engineering concepts (thinking not just about this PIC course, but all of the IE courses you have taken)?
4	On a scale of 1 to 5, how much experience/familiarity do you have with video games (where 1 is very little and 5 is a lot)? Explain.

Table 1. Reflection Questions Completed by Students

Results

The developed mini-project was assigned to students in Production and Inventory Control in the Fall 2020 semester. Thirty-one students completed the mini-project. In Question 2 of the submitted reflections, 25 of the 31 students stated that they found the video game more helpful to their understanding of factory flow concepts than the Arena simulation model that they used in class. Of the remaining six students, two said they found the two methods equally useful and four preferred the Arena simulation models.

The class average of the self-reported video game familiarity obtained through Question 4 of the submitted reflections was 3.33. Interestingly, the average for the six students who did not find the Factorio videos more helpful to their understanding of factory flow concepts was exactly the same,

3.33. This suggests that a student's familiarity with video games may not affect their learning preference.

All 31 students responded positively to Question 3 of the reflections, stating that they video games have potential to improve their learning in their industrial engineering courses. Two students did express concerns in the cost and in some of their professors' abilities to use the technology necessary to effectively present material through video games. Most comments were similar to this student's: "Using video games simulations would be very helpful in understanding some of the IE concepts as a lot of these concepts are very analytical and complex; some form of visual representation would make it more interesting and easier to comprehend." Many students mentioned being visual learners, such that the Factorio videos helped them immensely. A few students also mentioned Virtual Reality (VR) games as a possibility for even more realistic visualizations.

Question 1 of the reflection asked students specifically how the Factorio videos helped them. Some of the condensed responses are shown in Table 2.

"I found the videos significantly improved my understanding of factory flows. Before the videos I knew how to use the simple calculation for WIP (WIP = CT*TH), however in a practical scenario I did not fully understand how to time the throughput rate. In addition, I was also was unclear on how we would reduce cycle time which is a goal in Little's Law. I found tracking a unit through the production easier to understand Littles Law."
"I feel like the video helped illustrate a lot of Industrial Engineering concepts with her breakdown on WIP and Throughput and why JIT is so important. While I knew IE concepts, watching … link various subjects together helped clarify things and show how interconnected this material is, which was an issue I was having other courses since things felt disconnected sometimes. A part of that was noticing a huge bottleneck of gears which showed theory in practice, not cranking out parts and focusing more on lean JIT systems to prevent things from getting clogged."
"First off, I thought the software looked phenomenal and the Realism involved in the programming was fantastic. I did understand a little bit from this and previous classes, but these videos helped me understand how factory flows work."
"Something about the video that I noticed right away is that the simulation is quite realistic. This helped me think about future projects that I would face in the real world as an Industrial Engineer. Utilization was something that I believed this video really highlighted as it was clear which parts of the assembly line had more activity by even just watching how frequently the mechanical arms would transport items at each individual machine."
"The videos were good simulations of an assembly line. In the first video, I enjoyed that the narrator used boxes to define some of the terminology we used in class, and she broke down the production process step by step. It was helpful that she showed what was going on inside each "workstation", along with how many of which material were needed and how long to build. I also liked that there were visual aids (BOM and flow chart) within the text to gain a better understanding of the process before watching the video. In the second video, the simulation helped me better understand throughput and cycle time in terms the entire system as opposed to each workstation."

Table 2. Sample of Student Response to Reflection Question 1

Summary and Conclusions

In summary, we have described the creation of an online lesson on factory flows, including videos created using the video game, Factorio. The lessons were completely online and did not take any class time to present to students. Students were asked to complete four reflection questions after completing the lessons. The submitted reflections indicated that students found the video game useful in helping them visualize faculty flow definitions and metrics. The students appreciated the use of the video game to demonstrate class topics.

The authors feel that this proof of concept was successful in a difficult Fall 2020 semester. The authors feel that the lessons could be made even more powerful by having students interact with the video game instead of only watching videos of another interacting with the game. This would need to be balanced with the time and cost requirements and the fact that not all students are equally interested or experienced with video game user interfaces. The lesson will be used again in the Spring 2020 semester, with graduate students to see how the results compare.

Future study will include study of the connection between the developed lessons and student outcomes. Measurement of possible correlation between the use of Factorio as a learning tool and accomplishment of student learning objectives will be the goal of the follow-on research. Such measurement was not a part of this pilot program but will be the main objective of the next iteration.

The success of this pilot program has encouraged the authors to continue to explore opportunities to use Factorio, and other video games, to help students visualize theoretical concepts. There are many opportunities!

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