Integrating Simulation Games and Virtual Reality to Teach Manufacturing Systems Concepts

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Abstract

Simulation games can be a catalyst for understanding manufacturing systems concepts among engineering students. Integrating manufacturing simulations with virtual reality (VR) allows students to visualize, manipulate and interact with computers and extremely complex data. This paper discusses the use of simulation to teach manufacturing concepts. We developed five physical simulation games for the different manufacturing environments (i.e., craft production, mass production, lean production, mass customization, and personalized production). We then developed corresponding digital simulations and integrated them with virtual reality technology. This paper focuses on the development of a virtual reality simulation for craft production. Manufacturing concepts such as inventory planning, production scheduling, and process improvement (Lean and Six Sigma methodologies) will also be considered. By comparing physical simulations with virtual reality environments, this paper provides insights into the applicability of virtual reality technologies in the education domain. Research activities will be integrated into undergraduate courses on manufacturing systems to support problem-solving skill development among students.

1. Background

Simulation games can be a catalyst for understanding manufacturing concepts among engineering students. Using simulation games allows students to experiment various manufacturing systems in a realistic setting. Moreover, simulation games can provide a means to engage students in classrooms allowing students to become active and interested in the topic [1]. Studies have shown that hands-on simulations can improve student attendance by 50% [2]. Several studies in the literature have developed physical simulations for manufacturing systems and processes. For example, hands-on activities were developed to compare and contrast craft production and mass production in the classroom [3]. Researchers have also developed a simulation that can be used to educate students and industry professionals on Lean manufacturing principles [4]. This study discusses the use of simulation games to teach Lean manufacturing principles [5].

Virtual reality (VR) has become popular in the past few years, as the hardware and software associated with it has become cheaper, faster, and easier to use, both in the consumer market as well as for research purposes. As devices get more affordable, the market is filled with new and different types of games to utilize the hardware. From education to training and therapy, many applications were not possible to this extent previously. In this project, the use of VR is dedicated to creating a richer and more immersive learning environment for the participants involved in the project.

Researchers have been using video games in educational settings for the purpose of learning and training [6,7]. This fast-growing trend is aided by the vast improvement in hardware capable of rendering increasingly realistic and high definition virtual environments. VR technology brings immersion and presence in virtual environments to the next level by allowing a user to experience fully a completely different world apart from their own. The use of VR allows for new perspectives in the human-computer interactions that otherwise would be restricted to interactions in only two dimensions [8]. This opens up new opportunities in how learning and training could be performed. Many researchers are looking into various aspects of VR such as immersion. Different combinations of VR control schemes with head tracking and mouse are compared and a study reported trade-offs between performance and immersion [9]. While a VR experience today is most often a single-user experience, one study demonstrated that having an interactive partner in VR could reduce the feeling of loneliness and that having a partner in VR who does not cooperate as expected would instead increase loneliness. This study also showed that an artificially intelligent virtual partner does not replace a human partner and can result in increased negative affect [10]. Tracking head movement in VR has been one of the standard input methods, allowing for aiming, moving and pressing buttons [11]. However, little has been done on the tracking of eye movements independent of head movement.

In the field of manufacturing, VR has been used for training employees the sequence of semiconductor manufacturing, for prototyping an aircraft engine, and for building a virtual factory

[12]. Combining virtualization and interaction makes VR an effective tool. Integrating manufacturing simulations with VR allows students to visualize, manipulate and interact with computers and extremely complex data.

2. Research Framework

The proposed research framework consists of three main steps (Figure 1). In step one, we examined real manufacturing systems. Based on these, we developed physical simulations of the manufacturing systems, utilizing LEGO kits. In step two, VR simulations of manufacturing systems were developed to mirror the physical simulations, allowing for a direct comparison between the two. The VR headset is equipped with eye-tracking capabilities allowing for the collection of data associated with the participants' eye movements in VR. Finally, in step three, eye tracking data and observations were used to build analytical models regarding the students' performance in the assigned tasks, their understanding of manufacturing concepts, their professional skills in teamwork, and the differences between receiving a physical experience and a VR experience.

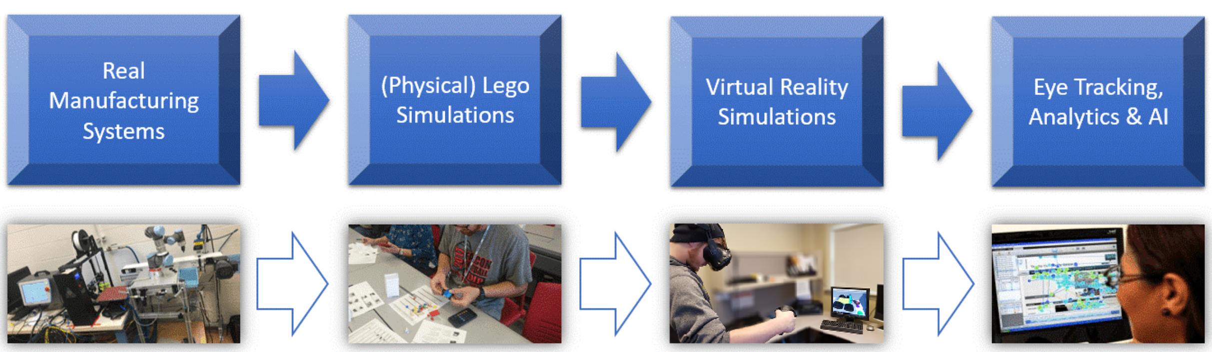

Figure 1. Research framework for teaching manufacturing concepts

One of the tasks of the physical simulations is called craft production. In craft production, participants engage in the craft production paradigms and learn problem-solving skills in design and manufacturing. In the physical simulation, participants are given LEGO kits, and they are asked to perform these tasks:

1. Some participants serve as "customers" while others serve as "manufacturers."

2. A customer orders cars and provides the manufacturers with a list of requirements for the cars (such as weight, colors, or must-have components) and the maximum cost the customer is willing to pay. The list of requirements chosen from the predetermined set are guaranteed to have at least one solution.

3. Using the available LEGO blocks, it is up to the manufacturers to design a LEGO car that satisfies the customer's requirements, while keeping the cost below what the customer is willing to pay, in order to make a profit.

The LEGO kit provided to the participants contains different options for the assembly of a car. For example, there are three types of tires with different weights and costs. The participants must first decide on the correct LEGO blocks in order to satisfy the requirements. A few example LEGO blocks and the manufacturing process is shown in Figure 2.

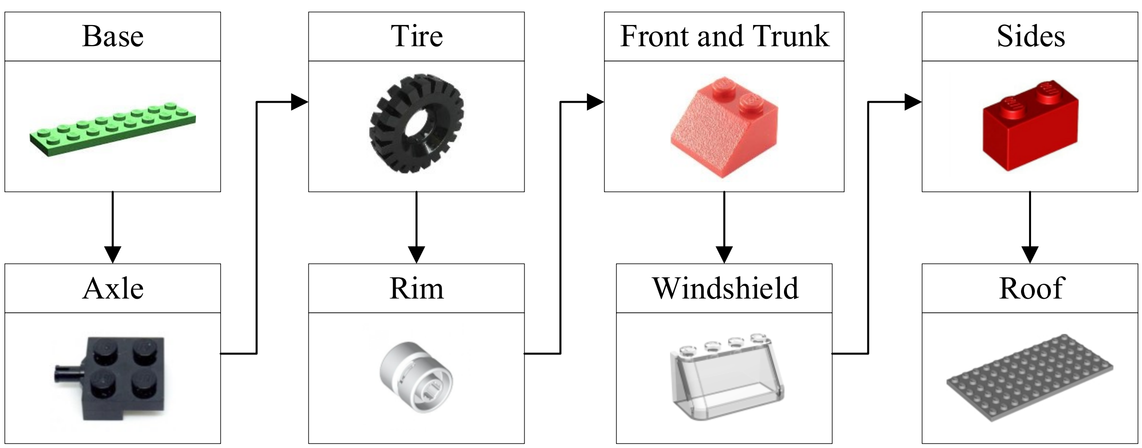

Figure 2. Main steps for the LEGO car assembly process

3. Virtual Reality Simulation

We have designed a VR simulation to closely mirror the physical simulation of the craft production process. The VR simulation is built by two undergraduate research assistants in the Unity game engine with the HTC Vive VR headset, wireless controller and motion-sensing base stations. A participant wears the VR headset while completing the simulation. In the simulation, the participant sees through the headset a virtual environment of a workstation, and is able to interact with the objects in the virtual environment, e.g. pick up a LEGO piece, using the wireless controller in hand.

In this craft production simulation, the participant is first presented with a set of instructions on craft production as well as on how to use the virtual environment. Once the participant is ready to start, the car order along with the set of customer requirements are presented to the participant. For example, the requirements could be:

(a) vehicle weight between 20 and 40 grams;

(b) material cost is less than or equal to $10;

(c) number of individual components is less than or equal to 2;

(d) vehicle must fit completely within the design footprint “parking space”;

(e) number of different types of LEGO blocks must be greater than 10;

(g) number of different colors for LEGO blocks must be 5 (exclude driver and wind shield);

(h) vehicle must have four tires (with axles), wind shield, driver, steering wheel, and roof.

(i) the customer is willing to pay $25.

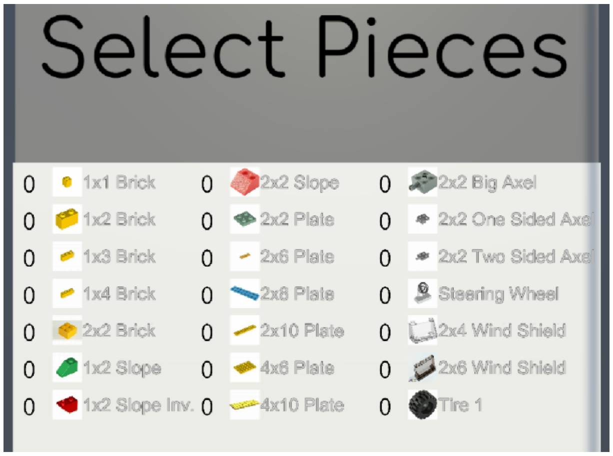

Figure 3. The LEGO pieces selection station, as viewed from the VR simulation.

The participant is then presented with a wall of LEGO pieces to choose from (Figure 3), and the selection is done by pointing at a piece with the virtual reality glove. Once the participant decides on the necessary pieces, the participant is taken to a series of workstations to complete the assembly of the product: Tire and Rim, Wheel and Axel, Base, Sides, and Roof (Figure 4). Each workstation is a separate room inside the VR. Participants are allowed to go back to any previous workstation and change their minds if they choose. In addition, a participant is able to go back to the LEGO pieces selection station and select new pieces at any time, by pressing the purple button on the right. This matches the physical simulation where participants are also able to go back to the LEGO kit box at any time and pick out new pieces.

The VR headset is fitted with eye-tracking capabilities. As a participant works through the simulation, the system tracks the participant's eye movements, including fixation points, latencies, and saccades. The Unity game engine also provides us with an exact timeline of which LEGO pieces the participant has looked at any given time in the simulation process. We use this eye tracking data to model attention and provide a better understanding of metacognitive process.

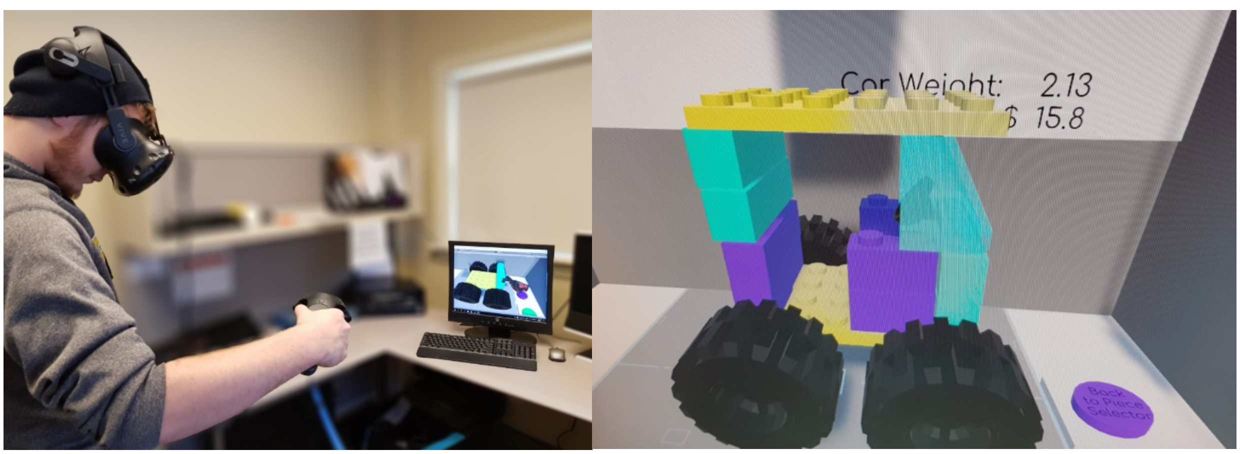

Figure 4. (a) a participant using the VR simulation to complete the craft production process. A screen shows what the participant is seeing. (b) a participant's view as the LEGO pieces are being assembled into a product.

4. Analysis

The primary goal of the development of the VR simulation is to provide a comparison with the corresponding physical simulation. We put together the craft production physical simulation and the craft production VR simulation and conjecture that both are able to provide a comparable experience for a participant. The participants are given the same set of instructions under both settings, and they have to complete the same tasks using the same set of tools (LEGO pieces). The LEGO pieces are presented either as real-life physical pieces, or inside a VR environment. Since VR is a relatively novel technology, a participant's previous experience with a VR environment must be taken into account. We held a sample run with one of our undergraduate research assistants through the VR simulation. Table 1 shows a summary of the amount of time it took him to go through each station in the simulation. From this preliminary analysis, we see that the research assistant quickly went over the instructions (as he was familiar with this project), and took a small amount of time in each of the first three car assembly stations. However, after reaching the Sides station, he realized that his chosen parts could not complete the assembly and conform to the requirements stated by the customer. The amount of time he spent correcting his mistake is noticeable in the increased time in the Sides station. Table 1 shows a sample run through the VR simulation. Time is recorded in seconds. The asterisks represent the fact that during this time, the participant has gone back to the LEGO pieces selection station and chosen new pieces.

Table 1. VR simulation results

Task	Start Timestamp	Duration
Read over instructions	0.0s	18.9s
Select pieces from the LEGO pieces selection station	18.9s	61.6s
Car assembly: Tire and Rim station	80.5s	37.8s
Car assembly: Wheel and Axel station	118.3s	39.8s
Car assembly: Base station	158.1s	9.7s
Car assembly: Sides station	167.8s	126.5s*
Car assembly: Roof station	294.3s	36.7s*
Completed assembly	331.0s	

We compared cycle time for both the physical and VR simulations. We defined cycle time as the total time to assemble a LEGO car, from receiving the instructions to assembling the last part of the car toy. For VR, we have conducted a user study with undergraduate students who are aspiring engineers. So far, we have collected the completed results from 4 participants, where the average cycle time was 14.33 minutes. For the physical simulation, we previously conducted a study in which 23 students (5 males and 18 females) participated. The average cycle time from the VR simulation is greater than the average cycle time for physical simulation (6.55 minutes). We suspect that this is due to the unfamiliarity of the participants with a VR environment and that would be reduced with practice.

5. Conclusions and Future Work

The use of simulation games for educational purposes has grown in recent years. This paper discussed the use of simulation to teach technical and non-technical manufacturing skills to engineering students. We built five physical simulations to teach craft production, mass production, Lean production, mass customization, and personalized production. In order to compare the advantages and disadvantages of physical simulation and VR simulations, we created a VR simulation of craft production that closely mirrored our physical craft production simulation. Future work will focus on recruiting participants from different engineering disciplines, randomly assign them to participate in either the physical simulation or the VR simulation, and perform metacognitive assessment of both groups. We aim to recruit ten teams of four students each to participate. The participants will first be asked to complete a craft production simulation individually, in either the physical setting or in VR, and then work together in a mass production simulation.

Acknowledgements

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