Developing a Virtual Reality Game for Manufacturing Education

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ABSTRACT

This paper describes the development of a virtual reality (VR) simulation game for educating engineering students in manufacturing. Undergraduate engineering students work on solving design and manufacturing problems and utilize professional skills to improve their overall performance and outcome. This research utilizes interactive and immersive VR technologies to develop a new integrated approach to understand problem solving in engineering students and determine if engineering students are attending to the correct elements while they are solving design and manufacturing problems. Furthermore, a player modeling technique is proposed to deliver an experience adapted for each student. The approach will be tested, validated and used to bridge the skills gap that exists for many undergraduate engineering students.

CCS CONCEPTS

• Applied computing → Computer games • Software and its engineering → Interactive games • Human-centered computing → Virtual reality

KEYWORDS

Serious game, educational game, virtual reality, player modeling

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1 Introduction

Manufacturing is the application of machines, tools and labor to transform raw materials to finished goods for sale or use. It is an important contributor to the economy as it supports all the other sectors of the economy and provides a wide variety of jobs. Manufacturing has evolved through several revolutionary models (known as paradigms) that are induced by new market and economy conditions, technology advancement, and social needs. Five main paradigms have evolved: craft production, mass production, lean manufacturing, mass customization, and personalized production. Craft production refers to the manufacturing of goods by hand without automation. Craft production is found in all societies and is defined as "creating exactly what the customer asks for, on demand, usually one unique product at a time." [7] In this paper, a single user paradigm is used.

We developed a craft production simulation for engineering education. While physical simulations of craft production have been utilized in the past [1], our simulation used current virtual reality (VR) technologies. After identifying a manufacturing system and the product, we designed a VR simulation game specifically for engineering students. The simulation game involved designing a product while conforming to given requirements. The activity involved designing and producing LEGO cars that satisfy customer requirements while keeping the total production cost low. The concepts included manufacturing system inputs and outputs, manufacturing processes, manufacturing layouts, and performance measures.

VR technology brings immersion to the next level by allowing a user to become fully immersed in a different world. The popularity of VR in recent years is helped by the introduction of lightweight and affordable VR headsets [6]. Serious games for the purpose of education, training and military applications have started deploying VR technology [9]. Researchers are looking into various aspects of VR, such as how players could interact with a fully 3D environment in a VR game [11]. Different input schemes are also examined, such as head-tracking [2] and the effects of locomotion methods on the player's experience [10]. Researchers have studied the effects of interactions with a partner in VR. While having an interactive partner in VR could reduce the feeling of loneliness, having a partner in VR who does not cooperate as expected would instead increase loneliness, regardless of whether the partner is human or an artificially intelligent (AI) agent [3].

2 Craft Production Virtual Reality Simulation

In manufacturing, craft production is a process in which the customer's demand for a unique product is exactly fulfilled [7]. In order to do this, an engineer must be able to identify customer requirements, constraints, and the necessary materials in order to produce a product that meets the customer's demand while keeping total cost below an acceptable level. This requires technical skills as well as professional skills such as innovation and creativity. Actual materials used in such scenarios can be costly for the purpose of engineering education. Therefore, simulations are often created.

To create a simulated example of a craft production process, we designed a VR simulation game of a LEGO car manufacturing environment. There are several goals of this simulation.

1. Provide students with a set of scenarios to practice their skills at craft production.
2. Use AI techniques to assist students in learning about craft production.
3. Through external observations and eye-tracking of students, understand problem solving in engineering students and determine if engineering students are attending to the correct elements.

The VR simulation game was built in the Unity game engine with the HTC Vive VR headset, wireless controller and base stations for motion tracking. For the purpose of this section, we used "user" to refer to a student or a participant using the VR simulation. A user wore the VR headset while completing the simulation. In the simulation, the user saw through the headset a virtual environment composed of a series of stations, and was able to interact with the objects in the virtual environment, e.g. pick up a LEGO piece using the wireless controller in hand. The headset was custom fitted with Tobii eye-tracking technology, allowing the system to identify the coordinates and objects that a user was looking at, at any given time during the simulation.

Since VR is a relatively novel technology, a user's previous experience with a VR environment must be taken into account. In this simulation, the user was first presented with a set of audio instructions on how to interact with the virtual environment. Once the user was comfortable, the user pressed a button to start the actual manufacturing process. A timer started counting at this time.

There were seven stations for the users to go through. Each station contained a desk and walls surrounding the desk. A user was able to teleport between the stations at any time by pressing buttons shown on the desks. The first station was the requirements station, where the user was given a set of customer requirements. A set of requirements could be that:

(a) vehicle must have four tires, windshield, steering wheel and roof;
(b) all tires must be small soft;
(c) vehicle base width and length must be 4 dots and 6 dots, respectively;
(d) vehicle weight must be between 20 and 30 grams;
(e) vehicle height must fit a sitting driver;
(f) there must be a minimum of 5 different colors on the vehicle;
(g) total vehicle cost must be $9 or less.

Once the user understood the requirements, the user pressed the green "next" button to teleport to the LEGO pieces selection station. The user was presented with a wall of LEGO pieces to choose from (Figure 1). Selection of LEGO pieces was done by pointing at them and pressing the trigger on the wireless controller. Each piece also came with a selection of colors, which a user could choose at the bottom of the wall. The number besides each piece on the wall represented the number of pieces selected.

The five subsequent stations were for the assembly of the vehicle. There were the base station, the wheel and axel station, the tire and rim station, the sides station, and the roof station. The LEGO pieces selected by the user appear in the corresponding assembly stations. The user went through each station to assemble the vehicle. Figure 2 shows a user working in the sides station to assemble the sides of a vehicle.

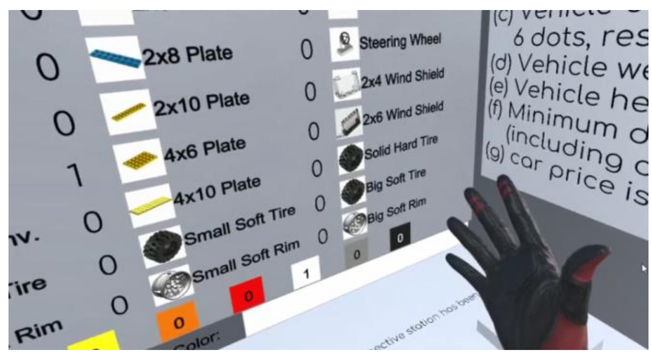

Figure 1: The LEGO pieces selection station, as viewed from the VR simulation game.

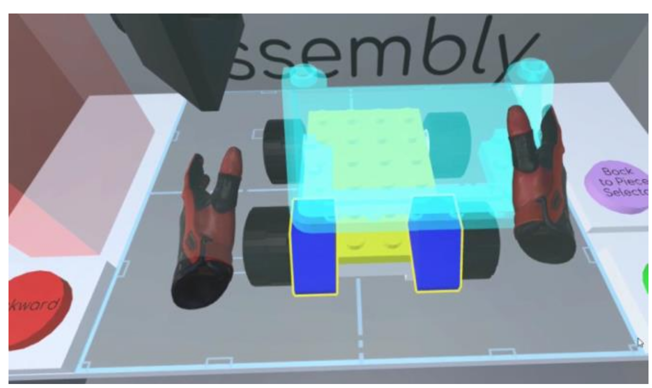

Figure 2: A user is working in one assembly station: the sides station.

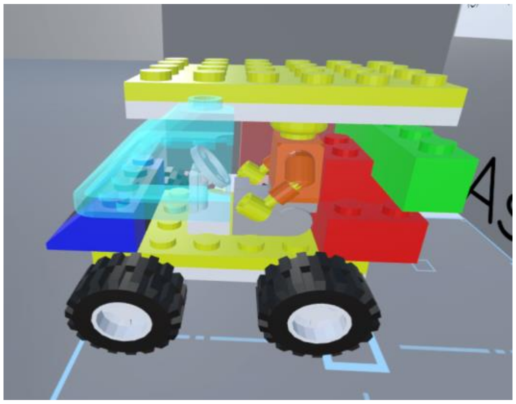

Figure 3: An assembled vehicle using virtual LEGO pieces.

At any time, a user was allowed to teleport to any previous station. A user was able to go back to the LEGO pieces selection station and select new pieces, by pressing the purple "back" button on the right side of the desk. A user was also able to throw away an unused piece by putting it into the red trash box on the left of the station.

Each LEGO piece was associated with a weight and a cost. This simulated a real-life craft production process where each material had an associated weight and cost. Total weight is often a customer requirement, and keeping the total cost below an acceptable level makes the production feasible. Users kept the weight and cost in mind when completing the task. The total current weight and current cost of the used LEGO pieces were displayed on the wall in front of the user. Once the user completed the assembly, the user pressed a "finish" button and the timer stopped. Figure 3 shows an example of a completed vehicle. The VR simulation game was created to mirror what a user would perform in a real-life craft production process.

3 Pilot Study

We conducted a sample run with one of our undergraduate research assistants through the VR simulation game. It took him 5 minutes and 31 seconds to complete the assembly while satisfying all the requirements. Based on this preliminary analysis, we set a limit of 20 minutes for a participant to complete the given task in VR. We conducted a pilot study with a participant pool of twelve undergraduate engineering students and prospective engineering students. All of the participants were men with an average age of 19.42 years old (*SD* = 0.90 years). All but one participant (92%) was in his first or second year of college (64% in their first year). The participants reported that they preferred engineering as a future career. Of these participants, eleven had complete data sets. However, five participants were not able to complete the required task within the 20-minute time limit, and we have analyzed the six successful participants.

In this study, the participants were first asked to complete a set of survey questions on conceptual knowledge, analytical knowledge, problem solving, and metacognitive awareness [1]. The participants then started the simulation in VR, where they examined the customer requirements generated in VR and worked on the task of building a vehicle. At the completion of the simulation, the participants were asked again to complete a survey similar to the one before, so that the results could be analyzed to see if learning occurred. The purpose of this pilot study was to examine the feasibility of a VR simulation in providing an environment of practice for students.

On average, a participant spent 13 minutes and 24 seconds completing the entire task. This is not surprising, as the participants did not have prior experience working in VR. Figure 4 shows a breakdown of the average time in seconds spent by participants at each station. Among the assembly stations, the participants spent the most time on the sides station. From the recorded videos of the participant sessions, we noticed that this station was where the participants started making corrections to their previous choices in the LEGO pieces as they started to examine more closely whether they were able to meet the requirements.

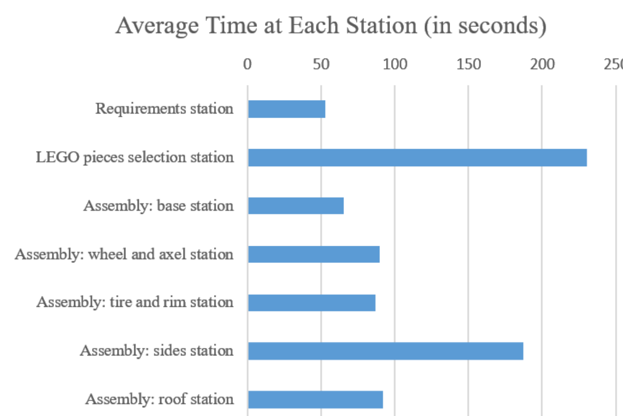

Figure 4: The average time in seconds by participants at each station.

4 Player Modeling

An advantage of using a game for the purpose of education is the interactivity. We are interested in exploring how modern AI technology can be used to benefit the educational experience. In the research field of AI technology in video games, player modeling is a broad research area that spans different scope, purpose, domain, and source [8]. When player modeling is deployed, the software environment monitors a player's actions throughout the game, collects player knowledge and behavioral data, iteratively builds a model of the player, and then uses the model to provide an experience adapted for the player. It is the use of AI techniques to construct a computational model of the player's knowledge and behavior [4]. Thue et al. [5] described an adaptive model to provide each player in a role-playing game a set of quests that tailored to the player's preferences.

In future work, we plan on adapting the concept of player modeling to engineering education by creating an AI-assisted VR simulation. An AI assistant will be running in the background at the same time as the VR simulation is run. As the student is making decisions in the VR simulation, the AI assistant tracks the student's actions and builds a model of the student. The AI assistant builds the model and uses the model at the same time to determine whether or when to provide assistance to the student during the VR simulation process in order to enhance student learning and decrease student frustration.

A model M(u) for a student u is a list of weights $[w_1, \ldots, w_n]$ corresponding to properties $[m_1, \ldots, m_n]$ that represents a particular student u. A model of the student consists of a set of important properties that are determined ahead of time by subject matter experts. Each property has a corresponding weight representing a particular student's value in that property. The meaning of a value is determined by what the properties represent. There can be multiple models for a single student, built on either dynamic information obtained during the task or static profiling information [4]. For example, $M_1 = [w_{11}, \ldots, w_{15}]$ is a model of the student's knowledge which is dynamically built, and $M_2 = [w_{21}, \ldots, w_{25}]$ is a model of the student's personal temperament, built through a pre-task survey.

A dynamic model is built in an iterative process. When a student starts with the task for the first time, the AI assistant has no models of this student, therefore the weights of each property for the model is set to a default value. To help the AI to adapt quickly, before the student starts a task, we will have the student answer a set of survey questions, designed to assess their background knowledge and their personal temperament. These survey questions are done in VR and the results are immediately used by the AI assistant to create a starting w_i for each model M.

As the student works through the task in VR, every time the student takes an action, that action is used to further fine-tune the models of student. This iterative process ensures that as the student works through the simulation, additional data is collected. The model is adjusted to become a more accurate representation of the student.

The purpose of the AI assistant is to help the student as the student is performing the task. The assistance materializes in the form of on-screen hints provided to the students at various decision points during the task. Because of the differences in student background knowledge and student personality, having the right hints at the right amounts is important in helping the student along while not being intrusive and immersion breaking. The AI assistant must also take into consideration the time the student had spent on a given task. Providing a hint too early hinders students' opportunity to discover the right answers themselves, while providing hints too late causes frustration. The AI assistant makes the decision on whether to show a hint to the student or not and which hint is shown. In addition, it could pick the null decision, which is to show nothing to the student at that point in time. The AI assistant can compare all possible decisions (show hints or not, which hints) and find out which decision best fits the current student's models.

5 Conclusion

In this paper, we presented a VR simulation game of a craft production simulation for engineering education. The game involved designing a product while conforming to given manufacturing requirements. We conducted a pilot study with engineering students to examine the feasibility of a VR simulation. We also presented a player modeling technique for the purpose of delivering an experience adapted for each student. Through further analysis of eye-tracking, we would like to determine if the students are attending to the correct elements. We hypothesize that the VR simulation game would bring a more engaging learning experience to the students, and future study will be conducted to test this hypothesis.

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