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Connected Learning and Integrated Course Knowledge (CLICK) Approach

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Abstract

This paper presents the results and findings of the connected learning and integrated course knowledge (CLICK) approach. The CLICK approach aims to provide an integrative learning experience by leveraging virtual reality (VR) and 3D simulation technology. Integrative learning is described as the process of creating connections between concepts (skill and knowledge) from different resources and experiences, linking theory and practice, and using a variation of platforms to help students' understandings. With this approach, the integration is achieved by using a virtual system that mimics a real-life manufacturing or service system. VR and 3D simulation technology are chosen because they enhance visualization, interaction, and collaboration which makes them suitable for educational settings. In addition, immersive technologies provide the sense of being part of the environment. They are effective educational tools because they give students the ability to interact with objects and space in real-time compared to traditional distance, time, or safety constraints. Virtual systems can be designed and created to provide an integrative learning environment via a theme that connects and transfers the knowledge across a curriculum. The paper will focus on the results of the project from two perspectives: technological and educational. The technological perspective will describe the research efforts of automatically generating virtual environments using the reinforcement learning (RL) approach while the educational perspective will summarize the results on the effectiveness of the CLICK approach on students' motivation, engineering identity, and learning outcomes.

Introduction

This paper presents the results of our NSF project entitled Leveraging Virtual Reality (VR) to Connect Learning and Integrate Course Knowledge (CLICK) in the Industrial Engineering Curriculum (award #1834465) [1]. The CLICK approach is an integrative curriculum approach. The approach leverages the benefits of immersive technologies, i.e., virtual reality and 3D simulation, to enhance student's motivation and improve learning experiences and outcomes. Virtual systems can be created using these technologies to provide a theme where students can learn the system principles and concepts across multiple courses in the curriculum. Immersive technologies make learning interactive and fun [2]. This approach is implemented in the Industrial Engineering (IE) curriculum because of the unique focus of this curriculum on systems [3].

The CLICK approach aims to address the problems in the current curriculum structure as well as challenges related to immersive technologies. The traditional course-centric curriculum structure fails to connect the fundamental topics that the students need to master and use to solve real-world problems [4], [5]. The problems of the traditional curriculum structure stem from the time and context separation and lack of an integrated theme or story across the courses [5]. In the IE curriculum, many concepts are connected. The student has to understand the prerequisite concepts to move on to the next concepts. For example, basic statistical concepts such as probability density functions (PDFs) are taught in fundamental statistics and probability courses in the sophomore/junior year. Students need this knowledge in the subsequent courses in the senior year. Courses like manufacturing systems design and analysis (e.g., factory physics), discrete-event simulation (e.g., arrival times distribution), and stochastic operations research (e.g., stochastic inventory management) all need statistical and probability knowledge. Usually, intricate examples about systems that imitate real-life situations are not feasible within the classroom environment. Moreover, random and separate in-class or homework problems fail to connect the concepts from different courses because of the time and context separation. Therefore, traditional teaching methods are not sufficient in establishing this needed connection between concepts as well as with practice (real-life applications) [5].

To improve learning experiences, educators seek innovative pedagogies to include in classrooms. For example, instructors use real-life case studies and class projects to connect the concepts within each course and provide an integrative experience. However, instructors could face the following situations when approaches like this are used: 1) the data is already collected and the students need to investigate different scenarios to design, improve, or solve a problem for the current system, or 2) the students have to collect the data from the system under investigation. The problem in the first situation is that the students are not given the chance to identify and collect the necessary and relevant dataset. Engineers need to identify and formulate the problem, identify the necessary dataset, and then collect the data in real-life situations. In the second situation, students usually do not have access to different types of necessary datasets, or it is risky to collect the data from the actual system.

Several studies have investigated curriculum integration, Bhatia and Constans [6] used a desktop steam engine to connect two junior-level courses. Constans et al. [7] used a green design project with a five-semester core curriculum where students look at the different design aspects of a hybrid powertrain. In both studies, the students needed to rely on their previous knowledge to complete the design of a steam engine or powertrain. In this case, the steam engine and powertrain provided the theme to connect the knowledge as they progress through different courses. The students indicated that the use of these physical objects increased their knowledge of course fundamentals. The objective of the CLICK approach is not just connecting the courses across the curriculum, but also making a meaningful connection between knowledge and practice by providing hands-on experiences and real-life settings through virtual systems. While these studies used physical systems, the CLICK approach uses virtual systems as a theme. Virtual systems provide a relatively cheap and less risky alternative compared to expensive and/or dangerous situations that might happen by interacting with actual systems. Some universities have built physical manufacturing systems to teach and train students on manufacturing operations. For example, the Department of Industrial and Systems Engineering at Auburn University created a laboratory called the automotive manufacturing systems lab [8]. In this lab, students build 273-piece LEGO vehicles while learning about Toyota production system principles. They provide hands-on experiences but require a large space (4,000 ft^2) and require 18 students to be present at the time of the experiment [9]. In addition, these labs are not portable which makes them not suitable for remote and online learning. On the other hand, immersive technologies are portable and can be used to build complex virtual systems [10], [11].

We hypothesize that the CLICK approach will transform how the IE curriculum is delivered. The CLICK approach will: 1) provide the needed connection between courses, therefore improve students' learning and satisfaction, and 2) provide the needed linkage between theory and practice through a realistic representation of systems, therefore improving engineering identity and generating work-ready graduates.

The other focus of this research project is automatically generating educational virtual environments that are personalized for individual students. The National Academy of Engineering (NAE) Grand Challenges of (i) advance personalized learning and (ii) enhance virtual reality, have the potential to transform how STEM education is taught and STEM contexts are experienced [12], [13]. However, the creation of personalized learning experiences is an expensive and time-consuming process that is a fundamental bottleneck for its use when scaled up. Unfortunately, there is still a significant amount of manual labor needed to create VR experiences, especially as the complexity and fidelity of the VR experience increases.

Procedural Content Generation (PCG) is an approach that has been proposed to overcome the costs and scalability challenges of content creation in VR [14]–[18]. This approach algorithmically generates content that is customized to a user's needs. While PCG methods have shown promise, a fundamental challenge is the generation of various contexts that meet the needs of a diverse student base. This is of particular importance in the engineering education domain wherein a fundamental concept (e.g., probability distributions), could be introduced in one course but have multiple causal implications in subsequent courses and ultimately, the workforce.

Many PCG methods use a supervised learning approach, where a large dataset of human-created content is used to train an algorithm to generate new variations [19]–[21]. However, large datasets do not exist for every potential application of virtual learning. In our research projects, Reinforcement Learning (RL) is used instead to explore the space of virtual content, which takes a trial-and-error approach to learning as opposed to a data-driven approach. This alleviates the need for large datasets of relevant human-created content.

The following sections present the results of the ongoing project from two perspectives: Educational and technological.

The CLICK Approach in Education

The IE discipline is focused on preparing the students in understanding integrated systems. It is difficult to provide intricate examples that imitate real-life systems with traditional teaching methods; therefore, simple and unrelated examples are typically used to explain the concepts. Consequently, the relationship between theory and practice is usually weak or even lost [22]. Immersive technology including VR and 3D simulations can be used to build intricate and realistic virtual systems. Immersive technology offers a sense of being part of the learning environment which makes it a suitable platform in educational settings. Immersive technology such as VR enhances visualization, interaction, and collaboration [23]. Many studies have shown the effectiveness of VR in enhancing students' understandings of concepts and reduce misconceptions as well as providing students the ability to visit virtual environments and interact with objects and space in real-time as compared to traditional teaching methods [24]–[27]. In addition, immersive technology can be integrated smoothly with online learning environments [28]. The CLICK approach leverages the immersive technology to build virtual systems. The virtual systems are the theme that transfers and connects the knowledge from one course to another in the IE curriculum.

The virtual systems are built to simulate a realistic manufacturing system and are developed by either a game engine, such as Unity 3D [29], or simulation software, such as Simio [30]. When built with Unity, the virtual system can be explored using a VR headset such as Oculus Quest

[31], [32]. Unity games can be viewed on a computer screen but will require rebuilding the virtual system to accommodate that. When built using Simio, the virtual systems can be explored on a computer screen and a VR headset (Oculus Rift, Rift S, or tethered Quest) which add more flexibility and scalability. This is especially important when teaching students remotely, and not all the students have VR headsets.

When selecting a system, the system should be complex enough to include challenges and activities that cover many problems and concepts from several courses in the IE curriculum, but not too complex to be created by the game engine and/or the simulation software. For our studies, we selected four main courses in the IE curriculum to study the effectiveness of the CLICK approach. The courses included the following:

1) Probabilistic Models in Industrial Engineering
2) Statistical Methods in Industrial Engineering
3) Operations Research
4) Discrete-event Simulation Modeling

It should be emphasized that the CLICK goal is not to include all the concepts from each course. It is impossible to include all the concepts from different courses in one module. The virtual systems include a selected set of main concepts from the courses. The virtual system can be included in a course as a project, case study, or assignment. The concepts in the virtual system are presented as exercises or challenges. The objectives of these challenges are aligned with the courses' objectives. Figure 1 shows an example of a virtual system along with example concepts from different courses.

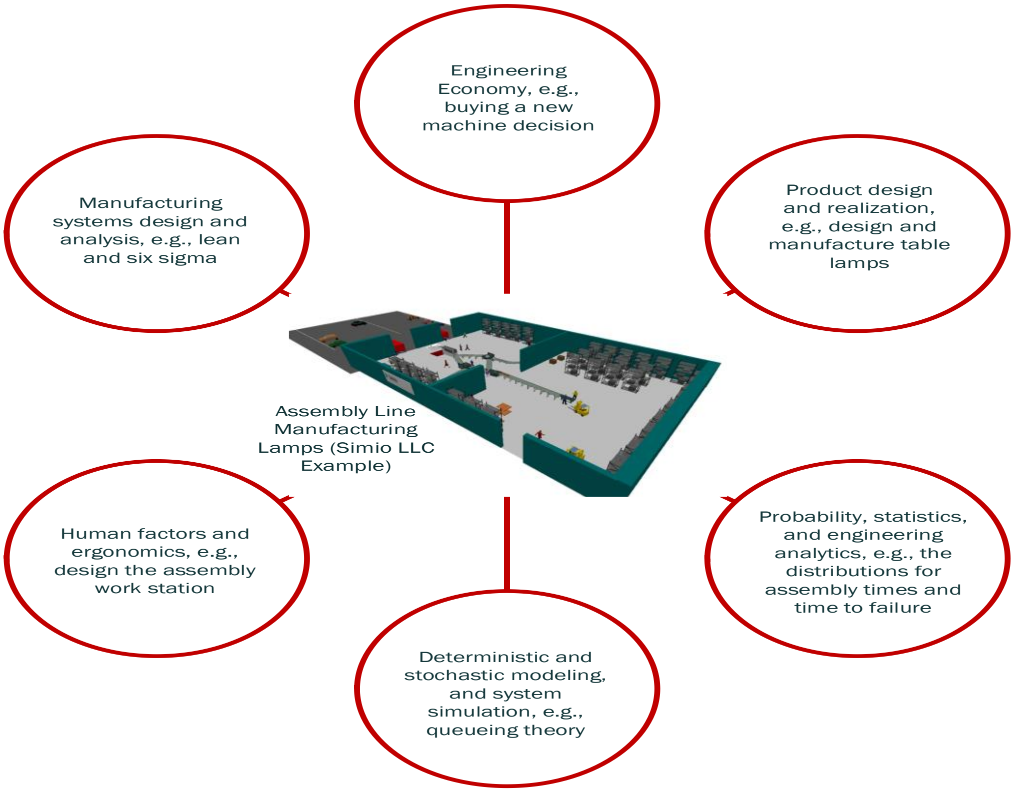


Figure 1. A virtual system built in Simio

We have developed a drill manufacturing system in Unity. The virtual system was used in the statics and probability courses and the plan was to use it in an operations research and simulation course. Due to the COVID-19 pandemic and the sudden shift to online and remote learning, a table lamp manufacturing assembly system was developed in Simio to be used in the operations research and simulation courses. The results of implementing the virtual systems are presented in our publications [33]–[35] and are highlighted below. The general data collection procedure and experimental design are shown in Figure 2. Two cohorts were used: Control and intervention groups. The control group involved students who were taught traditionally while the intervention group students used the virtual systems. Instruments including surveys and tests were used to collect students' demographics and personality characteristics, and to measure motivation, engineering identity, and knowledge gain.

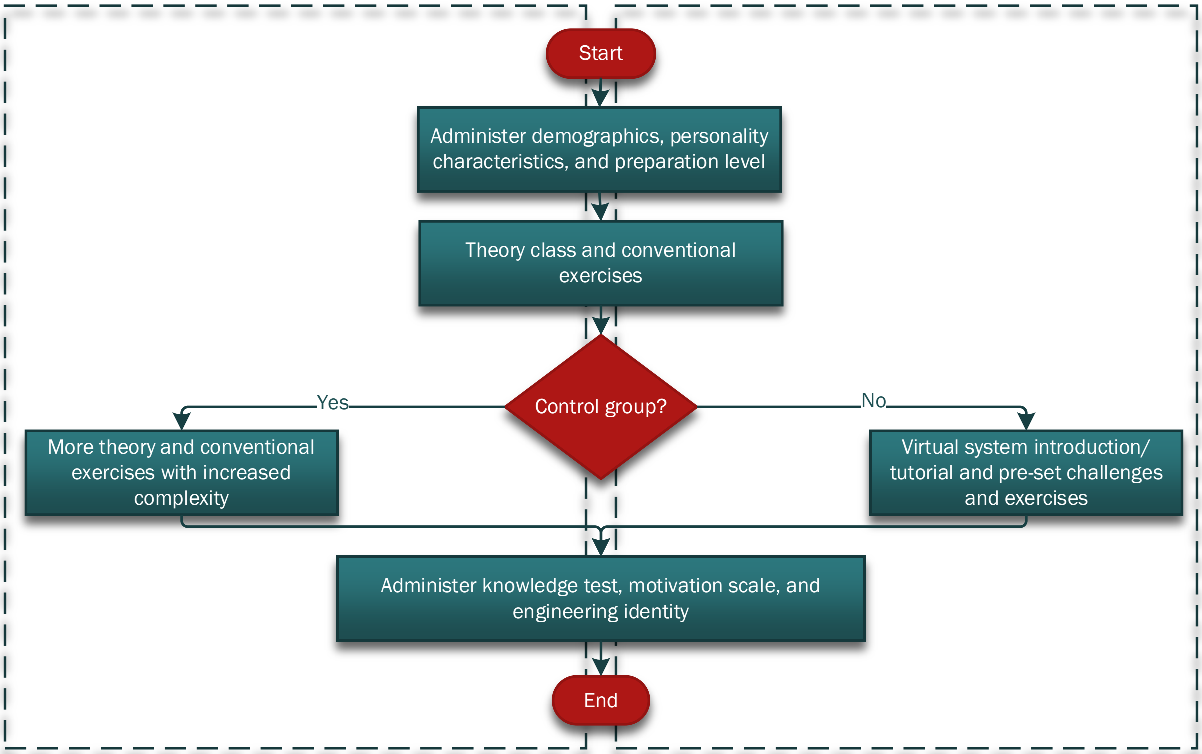


Figure 2. General data collection procedure used in this project

Our ongoing investigations [33]–[35] on the effectiveness of the CLICK approach have improved the students' motivation compared to a traditional teaching group. However, there were no effects on engineering identity and knowledge gain. The results showed that participants in the intervention group reported a statistically significantly greater Confidence and Satisfaction than the control group [34]. The intervention group students showed a good level of understanding of the concepts based on their self-assessment and grades [33]. The grades of the students were positively correlated to the students' motivation and engineering identity [33].

Content Generation of Virtual Reality Applications

The focus of the Procedural Content Generation (PCG) part of the project has been to use a Deep Reinforcement Learning (RL) approach that can generate virtual environments of multiple contexts that are connected by an overarching theme. This approach can dynamically accept input from the user that dictates what context the RL agent should generate as well as certain parameters of the environment for that context. The agent then builds an environment that has been validated via simulation to satisfy these parameters. In our experiments, Proximal Policy Optimization (PPO) was the particular RL approach chosen, as it offers a favorable tradeoff between sample complexity, simplicity, and wall-time [36]. Figure 3 shows the flow chart of this model that can generate environments in two contexts, a grocery store, and a manufacturing facility.

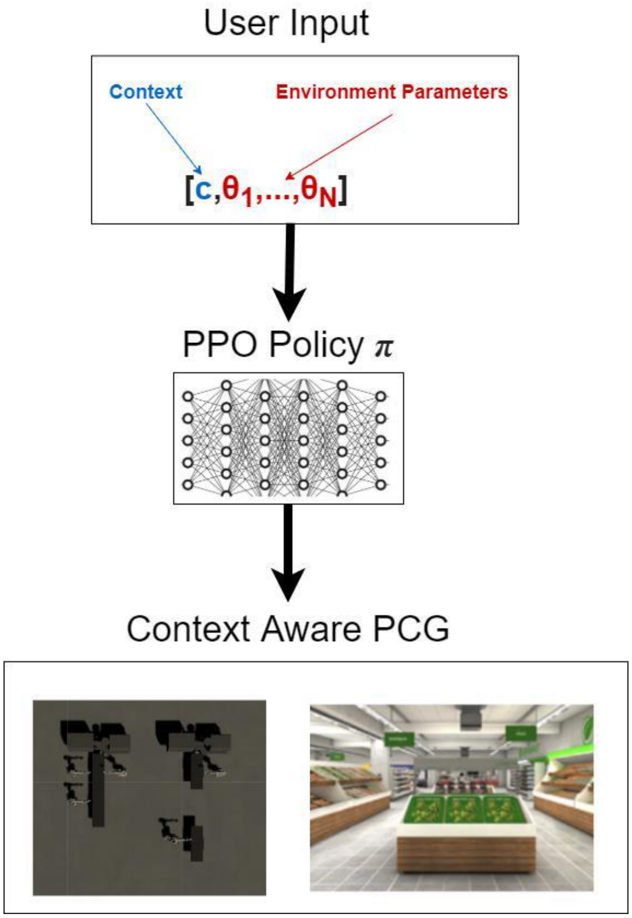
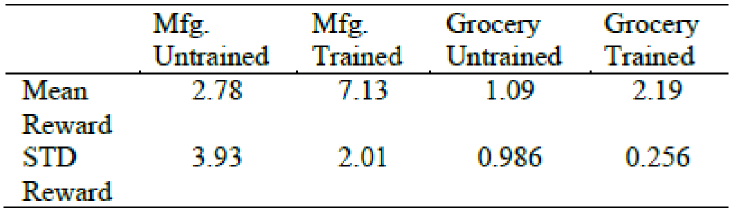


Figure 3. Flowchart of RL PCG approach

Our experiments showed that the agent learned to create valid environments in both a manufacturing and grocery store context that dynamically accepts user input of parameters the environment should have. Figure 4 shows the performance with respect to the reward function after training compared to the performance before training, and in both contexts, the agent showed the ability to significantly improve upon the baseline reward.

Table 1. Results of RL training



	Mfg. Untrained	Mfg. Trained	Grocery Untrained	Grocery Trained
Mean Reward	2.78	7.13	1.09	2.19
STD Reward	3.93	2.01	0.986	0.256

Although our experiments have demonstrated the concept on a simple example, the results show promise in the ability of RL-based PCG to dynamically create personalized educational content without the need for a large dataset of human-created examples. Adopting this approach for more complex virtual environments has the potential to allow for the scalability of personalized virtual educational content.

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