Student Response to the Introduction of Programmable Logic Controllers Through the Use of a Virtual Engineering Laboratory Environment

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Abstract

The Mechanical Engineering (ME) Department at Mississippi State University has recently begun to explore new options for exposing students to Programmable Logic Controllers (PLCs). After searching through a variety of commercially available PLC training options, ME selected a virtual PLC engineering laboratory environment called Factory I/O by Real Games. Factory I/O is a three dimensional, virtual, factory simulation created for the purpose of training students in automation technologies. The selection of this software was based on its ability to allow the instructor or student to build custom factory automation scenarios called scenes. These scenes can then be programmed using a variety of PLC coding environments and/or hardware. In addition, ME selected to use a Factory I/O compatible software PLC that allows students to program in ladder logic, function block diagram (FBD), or statement logic (STL), all common PLC programming languages used in industry. Finally, the student's PLC program can be executed while interfacing with the Factory I/O virtual factory scenario to test the program in a simulated real-world environment. This simulation includes many physical properties such as gravity, force, mass, and friction between surfaces all rendered simultaneously while the simulation is running. This feature also allows students to interact with their simulation in real-time, enabling them to explore how their programs will react to unexpected situations or inputs. The virtual environment alleviates many of the restrictions and costs of PLC training with physical equipment. With over fifty modular options of objects to place in the scene, students can be exposed to a wide variety of factory situations. Factory I/O has been in use for two semesters and student feedback was collected immediately following its use each term. The initial student response to this software and approach to PLC training has been extremely positive.

Keywords

Virtual, Laboratory, environment, factory, plc

Introduction

Virtual learning environments (VLEs) are an exciting new tool in experimental, lab-based education. For a technical material base like engineering, VLEs alleviate many challenging aspects of learning that are difficult to replicate in the real world. Common obstacles in experimental education involve limited time and confined spaces.[1-2,6-7] So for any scenario where the setup requires a long preparation, or the real-world application has too large a scale to replicate, physical setups become impractical. This is where the flexibility to create an identical layout to physical systems in a virtual environment is applicable.[6,8] Previously, such topics as factory production lines would be taught piece-wise at a micro level, leaving the student to stitch together their own concepts of the full system. VLEs make possible a curriculum based on the macro level which conveys better understanding of the entire system.

The argument against VLEs, especially in lab-based applications, is that the level of understanding and grasping of concepts is diminished compared to physical environments. That there are aspects of conducting real world experiments which cannot be replicated in a virtual setting is not in question. Physical experiments uniquely demonstrate the obstacles present in any process proposed for analysis.[1-3] Collecting data and performing tests tangibly means introducing uncertainty into any results. Additionally, time to completion is significantly greater for any real-world experiment, giving students a realistic understanding of the applications of the material. Tangible lessons relating to topics like mechanical advantage have been shown more effective with a real-world setup.[5] However, these are not reasons to disqualify virtual options in education. A computer based setup gives freedom to the experimenter, and instead of being bogged down with setup and careful observation, data is instantaneous and clear.[9,10] The link between a given lesson and the experimental outcome is more direct.[6] One study on scientific and engineering education using physical and virtual methods had this to say on VLEs: "In virtual laboratories, students can also directly link unobservable processes to symbolic equations and observable phenomena, which encourages them to make abstractions over different representations".[1] Moreover, the argument that physical education brings a greater conceptual understanding over virtual options has been found insufficient. A university in Cyprus conducted a study of undergraduate students enrolled in an introductory physics course which traditionally had been taught with a physical lab supplement. For the study, divided into two groups the class went through the same material from the same lecturer; the lab portion also was delivered from the same person for each grouping. Virtual vs. physical interactions with the experiment was the only difference in the course. The results taken from the pre and post evaluation in conceptual knowledge of material yielded near identical scores from each group of students.[2] There can be no discernable hindrance in the use of a virtual setting for experimental testing in the pursuit of student conceptual understanding.

Factory I/O is a VLE built for the purpose of training students in Programmable Logic Controllers (PLCs). It is an appealing VLE due to the simple user interface and clear system design. Developed by Real Games, Factory I/O is designed to allow a user to build a realistic manufacturing process, program, and test their creation. The program comes with a robust physics engine capable of accurately applying properties such as mass, gravity, force, and friction to the user specified systems. Additionally, this program allows for real time manipulation of objects, even during programmed execution. Giving students the ability to change and alter their work while in operation makes for a safe observation to unexpected inputs. This can lead to better designed systems which can account for random events without damaging physical tests. An example of the Factory I/O interface can be seen in Figure 1.

Figure 1: Example of the Factory I/O User Interface

Factory I/O is available in a variety of different licensing options including single seat subscription, single seat permanent, internal floating, and cloud-based floating licenses. Students are able to download the Factory I/O package to their own computers, and are not required to be in a computing lab. Factory I/O is compatible with several different programming methods and languages, allowing for varied coding solutions. There are also many different versions, all corresponding to the brand or type of PLC used. Factory I/O is still beholden to the shortcomings of virtual education. Uncertainty is an example of a real-world consideration that Factory I/O cannot realize. Based on this the ME department has selected a package that allows for coding in ladder logic, functional block diagrams, and statement logic to improve broadness in PLC training. All three of these languages are common in industries utilizing PLC automation. Benefits for computer-based modeling of automated systems training have been realized since the turn of the millennia. A web-based solution to system programming and implementation entered development in 2001 for undergraduate engineering education. The University of Missouri-Rolla created a web-based tool to connect distance students to a physical laboratory for programming experiments with a conveyor belt and light sensor system. Distance students could complete their programming requirements and queue for input into the physical lab setup. Additionally, a rudimentary virtual simulation model was created so that students could evaluate how their program should react in the real world.[3] This is exactly the setup proposed by the Mississippi State ME department, with all students using the VLE Factory I/O. Where UMR sought to facilitate a small physical lab with virtual testing, our department will use Factory I/O to study much larger systems completely in the virtual realm. Insertion of this curriculum will create a new avenue for up-to-date PLC education concurrent with uses in industries and will be improved and shown effective through student feedback.

Implementation

During the spring and fall semesters of 2018, students were introduced to PLCs using Factory I/O and two different PLC programming languages. The spring class was introduced to Function

Block Diagrams using the software PLC built in to Factory I/O called Control I/O. This software PLC is very user friendly and has good documentation online including visual aids for each function. However, Control I/O is limited to one PLC language, Function Block Diagrams. This graphical programming language uses blocks which represent a variety of sensors, actuators, memory, and logic functions. These blocks are then visually wired together in order to make logic statements. Figure 2 shows the coding environment for Control I/O with some sample logic diagrams already created. The fall class was introduced to a different, more prevalent, PLC language known as Ladder Logic. For this class a different software PLC, known as WinSPS-S7, was utilized. The WinSPS-S7 software PLC allows for coding to be done in 3 different PLC languages. These include Functional Block Diagram, Ladder Logic, & Statement List. The WinSPS-S7 software, shown in Figure 2 is not as intuitive as Control I/O but the inclusion of ladder logic as well as the other two languages significantly increases the training possibilities. It should be noted that WinSPS-S7 also allows the user to select which language they wish to code in at any time. This means that a user can be coding in ladder logic and simply select functional block diagram and the software will instantly translate the current code into the new language. For the purposes of this course the focus was solely on Ladder Logic due to its prevalence. Ladder Logic is also a graphical programming language which employs symbols with addresses to represent the sensors, actuators, memory, and logic functions within the automation system. Again, these symbols are wired together to form logic statements in the form of a ladder diagram, also seen in Figure 2.

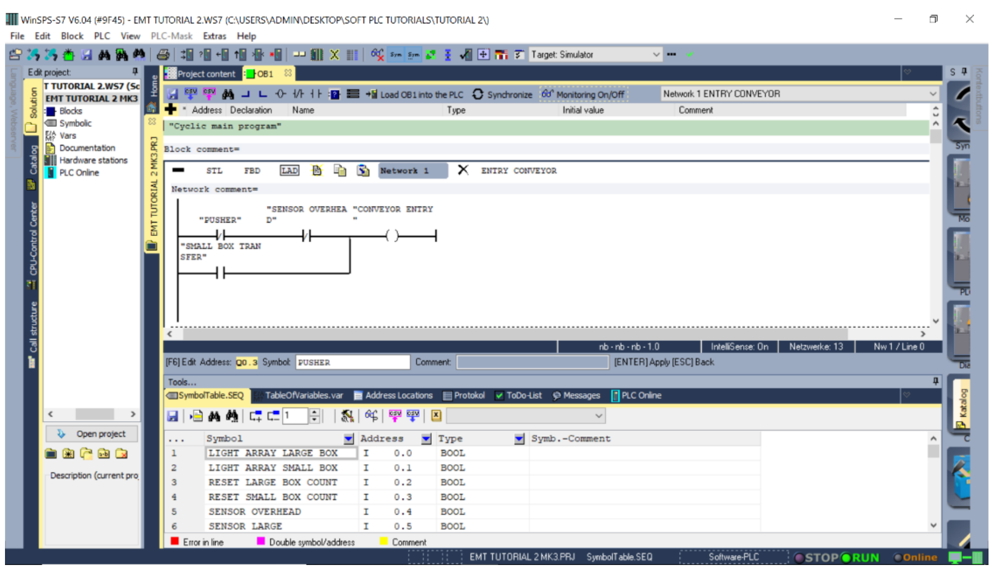

Figure 2: WinSPS-S7 User Interface w/ Ladder Logic

After being introduced to these programs and languages students in both semesters were guided through an initial PLC programming scenario using Factory I/O. This scenario was pre-built by the instructor. The instructor also guided students though programing the PLC for the given scenario. Finally, students were tasked with programing their own solution to another pre-built PLC scenario. An example of a one of these scenarios can be seen in Figure 3. In this Factory I/O scene students were tasked with sorting boxes by height as they exited the system.

Figure 3: Example Factory I/O Student Scenario

Student Survey & Response

Following the final PLC exercise each semester students were asked to complete a short survey about their thoughts on using the software. Table 1 below shows the questions from the survey given. The first two questions had options of yes and no, while the remaining three questions used a five-point Likert scale with 5 meaning strongly agree. Students were also asked if they had any comments or thoughts about Factory I/O, use of this type of software in the classroom setting, or other topics where they would like to see software like this use in. In total 157 students responded to the survey across the two semesters.

Table 1: Factory I/O Student Survey Questions

Q1	**Have you been exposed to programmable logic controllers (PLCs) before this lab?**
Q2	**Have you ever used anything that you would classify as a virtual engineering laboratory simulation/environment?**
Q3	**After being exposed to Factory I/O, I think this tool would enhance the quality of instruction for this material/topic.**
Q4	**For this topic/material, I think software like Factory I/O is more useful in my training due to its ability to create a realistic, large-scale, complex, customizable testing environment versus a small-scale, limited scenario with a piece of physical equipment.**
Q5	**I enjoyed exploring and using Factory I/O.**

The purpose of the first two questions was to establish if the students were familiar with the topic of PLCs or have had experience with a VLE prior to this course. As you can see in Figure 4, 76% of students have yet to be exposed to PLCs at this point in the curriculum.

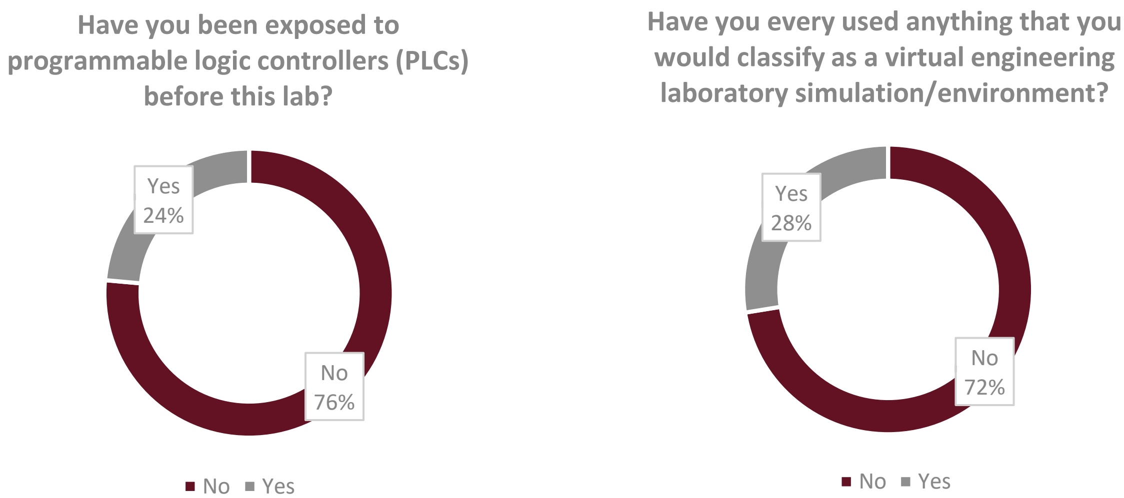

Figure 4: Student Response to Questions 1 & 2

Also, we can see from Figure 4 that only 28% of students had previously been exposed to a virtual engineering laboratory simulation/environment. The final three questions focused on the students experience and options of Factory I/O. Each of these questions were formatted in a Likert scale and presented to the students. Student responses were taken and compiled to complete the evaluation. Question 3 addressed how students felt Factory I/O performed as a plc education as opposed to other methods. The fourth question was posed to gauge whether students preferred a virtual education model to a more traditional physical setup. The option for a full-scale education compared to a limited scope physical setup was positive for students, and this question received the highest Likert average score. Finally question 5 evaluated the students' enjoyment using Factory I/O. Based on the final Likert scores, student response to Factory I/O and plc education was strongly positive. The average Likert score for each question is displayed in Figure 5.

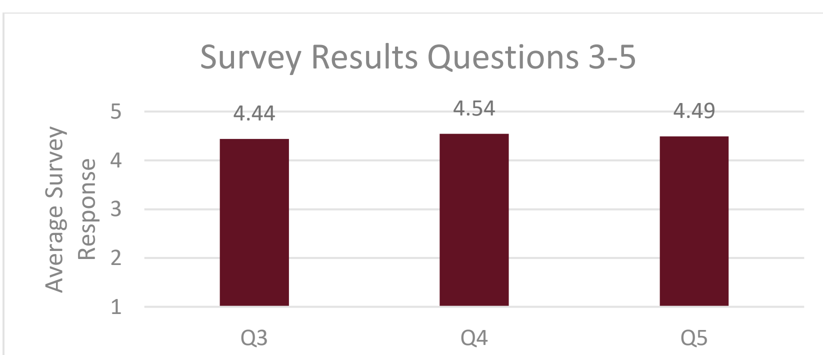

Figure 5: Student Response to Questions 3-5

Finally, below is a selection of student comments which also mirror the results of the survey.

> “Really awesome and helps visualize the ladder logic and PLC programming. Plus, it's helpful to be able to customize each "scene" to create personalized programming challenges.”
>
> “I really enjoyed getting to program a line of equipment and then get to go into Factory I/O and watch what I just programmed all start to work.”
>
> “The software was engaging enough that I have chosen to experiment with it on my own time.”
>
> “The physics engine in the software seems to be very well-refined and realistic. Factory I/O was a great PLC software to learn on because of its components' versatilities.
>
> “This is an epic software, it's educational and rather "up our alley" when it comes to programs! This should be a must have for schools to replace decaying learning techniques.”

Conclusion

The student response to the Factory I/O software has been extremely positive in its first year of implementation. Overall the students agreed that they thought the software was useful, enjoyable and enhanced the quality of instruction on this topic. Keeping in mind the that a large majority of students were not familiar with the topic or a virtual laboratory environment the level of student enjoyment and enthusiasm for Factory I/O as a tool for introducing PLCs to engineering students is very encouraging. Moving forward, the Mechanical Engineering (ME) Department at Mississippi State University plans to continue expanding its PLC introduction using Factory I/O as well as exploring other curriculum topics that may benefit from a VLE.

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