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Design and Preliminary Evaluation of Portable Kit for Programmable Logic Controller Education

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Abstract

PLC control programming is a complex cognitive skill that requires hands-on experience to develop proficiency. Successful automation/control engineers must know how to write PLC programs to control and troubleshoot the process being automated. Often, because of limitations in equipment availability, students must share equipment. Also, in academic settings, sometimes lecture and lab times are separated by a period of days, leading to decay of knowledge. To increase access to PLC technology, an educational tool kit called Portable PLC is being developed. The vision for Portable PLC is to create an open platform that instructors and students can use to design, build, experiment, and learn about programmable logic controllers during lectures and labs or at home, anytime and anywhere. Thirty-five portable PLC kits were designed and built. The kits were evaluated by 39 undergraduate students. Pre and post tests were used to assess their understanding of timer instructions, specifically the Timer On (TON) instruction. Students made statistically significant learning gains as a result of using Portable PLC, and rated the kit positively in terms of its effect on helping them to learn PLC programming, ease of use, allowing them visualize the process, motivating them to want to learn, and relevance. Most importantly, they responded that they wanted to see more tools like the portable PLC kit.

Motivation

A programmable logic controller (PLC) is an essential part of automation and at the heart of every automated and semi-automated manufacturing system. PLCs make process automation possible by orchestrating and synchronizing processes to ensure that every activity happens in a controlled and coordinated manner.

PLC programming is quite different from programming in languages such as Java or C. A PLC is a solid-state control system with a user-programmable memory, used to read input conditions and set output conditions to control a machine or process [1]. To write a PLC program, engineers need to know not only PLC programming syntax, but also the functions and general characteristics of the many hardware devices (such as different types of sensors and motors) that can serve as input or output (I/O) devices.

To become proficient at PLC programming, engineering students need to become familiar with functions and general characteristics of hardware devices, to understand how PLC controllers process programs, to be able to interface I/O devices with a PLC, and to be able to understand the control requirements of an application and write control programs accordingly. Hands-on experience with PLCs and I/O devices is needed to develop these skills.

Although programmable logic controllers are not large devices, they need to be interfaced with input/output (I/O) devices—such as motors, conveyers, actuators, and robot arms—to operate. The I/O devices can be bulky and expensive. As a result, student access to hands-on PLC training is heavily dependent on lab and equipment availability.

One approach to alleviating limitations in equipment availability is to make PLC education virtual. For example, LogixPro (http://www.thelearningpit.com/) employs animated educational simulations of processes, such as traffic control and batch mixing, to show how a ladder diagram relates to an automated process. Students can start and stop the animations, and study the corresponding ladder diagram for certain conditions or cases. In addition, ____ has developed an Integrated Virtual Learning System for Programmable Logic Controller (Virtual PLC). This web-based system uses a combination of animations, simulations, intelligent tutoring system technology, and games to teach about programmable logic controllers [2, 3, 4]. Both of these systems are good examples of how technology can be used to help students learn simple PLC programming concepts. However, for learning to write complex programs, there is no good substitute for hands-on experience programming a real PLC.

This paper describes an effort to design and build a low-cost portable PLC kit with quick-disconnect modules for teaching basic I/O devices and to evaluate the developed kit and instructional support materials. The kit consists of (1) controller module, (2) interchangeable special function module, and (3) plug and play I/O interface—all integrated in a portable box for easy transport. The controller module contains an industrial programmable logic controller and power supply unit. The special function module is connected to the controller module through a plug and play I/O interface. Three special function modules will be available: (1) basic I/O module, (2) sensor module, and (3) automated systems module. Figure 1 includes a diagram and photo of the layout of a PLC kit with a basic I/O module.

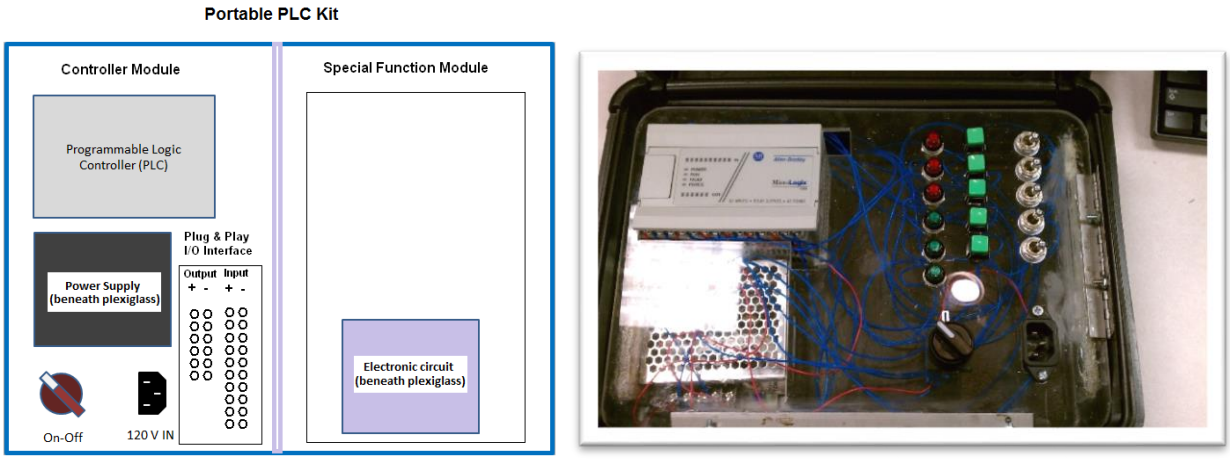

Figure 1. Diagram and Photo of Portable PLC Kit Layout (Basic I/O Module).

Evaluation

Portable PLC was incorporated into classroom instruction for two Automation and Robotics classes of about 40 students each (Figure 2). Students used the Portable PLC units in groups of 2 or 3 to complete exercises on concepts presented during the lectures for a period of six weeks. Afterwards, 82 students completed an opinion survey rating various aspects of their experience using Portable PLC on a 7 point Likert scale (1=strongly disagree; 7=strongly agree).

Figure 2. Students using Portable PLC during lecture.

The mean responses to the survey questions are shown in the figure below. Student ratings were positive for all items. In general, students felt that using Portable PLC and the associated practice questions helped them to learn more about PLC programming and that the hands-on experience helped them to visualize the process. They felt that using Portable PLC was useful and wanted to have more tools like it available.

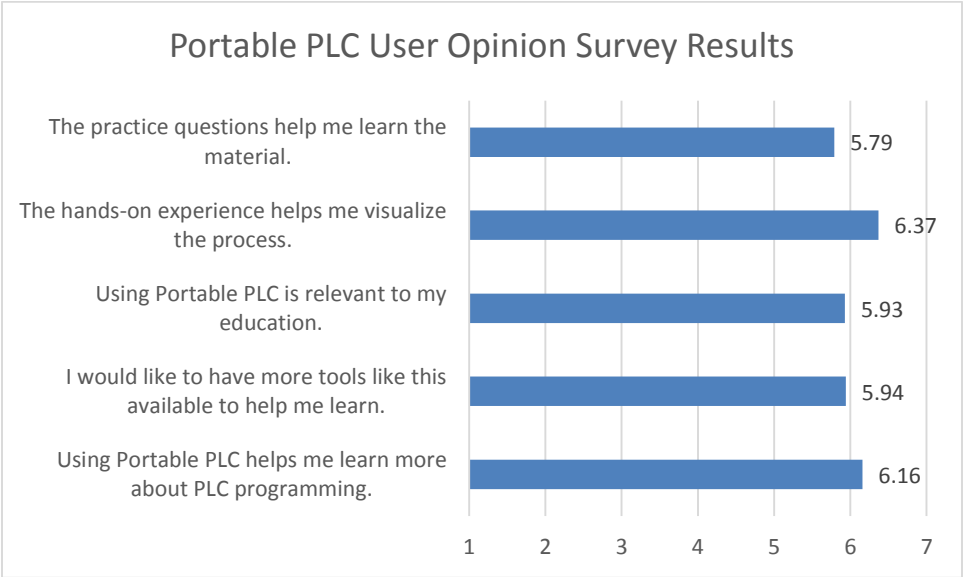

Figure 3. Mean responses to opinion survey questions.

Student Comments

In students' responses to the question "The most helpful thing about this teaching tool has been:" a common theme was that the students felt that Portable PLC helped them to visualize how the PLC works and to test their programs. Below are their responses:

- Visualization of processes.
- You get to see it done right in front of you, and hands on visual of it helps me understand and learn better.

- Having a PLC to work with to test in class exercises or with homework.
- Using the PLC in class & lab helps me visualize how to write programs on the test & homework.
- Writing Ladder Logic Diagrams
- The ability to write and test coding.
- The virtual PLC
- Seeing the actual material being used and seeing everything helps to visualize the problem.
- Hands-on interaction
- Having the hardware to test out the program is nice. It is easier to troubleshoot.
- Allowing me to physically run the programs
- Being able to visualize and test my programs.
- Hands on experience in the classroom
- Strong visual aid
- Being able to see how the PLC works and if my code is proper.
- Being able to compare program performance with program intent
- I can see the results and adjust from there
- The ability to test my efforts on the PLCs
- helps us learn by getting hands on experience
- Using the PLCs in class
- Being able to apply what I learn and check my understanding.
- To be able to learn hands on how the program interacts.
- Be able to check my understanding of the concepts and materials.
- being able to visualize the process
- Being able to actually see if our programs work.
- To get instant feedback on a program.
- Being able to see the ladder logic and how it reflects on the Portable PLC is the best way for me to learn this.
- The practice of programming
- The usefulness of this being used in a practical situation.
- It helps to keep the tools straight (i.e. which command is examine-if-closed, examine-if-opened, etc.).
- Seeing how the PLC actually works and being able to see your program work or not work.
- Its ability to relate theory with application.
- Hands on Experience makes the learning process easier.
- Ease of use while connecting it to the computer.
- It really helped me visualize and understand what we were actually programming. It was useful to have practice questions that are relevant and examples to real-world problems. It's definitely helpful to have a tangible tool that is affected by switches or buttons you press rather than just clicking and watching lights change on a screen.
- Hands on application in class. You get to work with a PLC outside of lab.

- The ability to get hands-on experience and practice with a PLC and better understand how to write and execute ladder logic diagrams. Furthermore, it provides an interactive experience to the class.
- The hand's on PLC programming has helped me visualize how switches work. weather they are normally open or normally closed. They also are a good representation of how we will use them in the real world when figuring out the problems in lab. Hands on with the PLC's kept me interested in this class.
- Practice vs strict memorization. Portable PLC allows for efficient learning of the material.
- Being able to test programs being designed in class.
- It would have been helpful if we were able to access it when class wasnt in session. Ex - like when doing homework and want to test the circuit. I learned everything i needed about the PLC from the lab with the full size PLC. Suggest putting some in the library to be able to be checked out like a textbook
- Its ability to relate theory to application.
- The hands on experience
- hands on learning
- Being able to play with the buttons and seeing the light on the portable PLC, and the programming software helps connect reality to the digital world. It is easier to grasp the concept rather than trying to visualize everything in class.
- Being able to see how the ladder logic works immediately and individually.
- feedback helps comprehend the process more quickly
- Being able to see what you have coded in the ladder logic actually work with outputs makes the process of learning much easier.
- Using the program with the PLC gave me a much better understanding what these are and how they work as I know several employers use these.
- actually being able to work the system and tools physically instead of just visualized how it COULD work. I learn quicker that way
- It was another tool to help me understand the basics of PLC. I struggled in the beginning of the class to grasp the fundamentals and Portable PLC helped a lot
- The ability to see what we learn in practice.
- Being able to have participate actually using the PLC's, gaining valuable hands on experience.
- Provides classroom practice with PLCs
- Being able to visualize the process and check your programming.
- It helped me more accurately visualize the inputs and outputs of a PLC device.
- It has been helpful because it allows me to have more time with a PLC.
- Immediate visual results in what you want the program to do.
- The use of visuals
- The interaction between the computer and the PLC really help emphasize what happens when you complete the program and download it.
- hand on experience
- Hands on learning is most beneficial to me.
- The hands on learning

- The PLC allows us to practice the programming more than just in lab and helps us to learn because of the hands on experience.
- I can see how it works.
- Being able to test my work, and seeing if I wrote the program right or wrong. This also helps me to visualize the homework like in lab.
- Visual description of what different parts of the PLC do.
- This tool gives you the ability to directly verify instructions.
- being able to test my progamming and get a visible feedback on whether it works or not
- Utilizing class time and the PLC to visualize the actual Process.
- The ability to design programs at the work station and test them.
- Being able to see the program actually work, or not, helps me to understand the process. It also helps for troubleshooting.
- Being able to program during class is very helpful when visualizing the programs while doing homework or taking test.
- Writing ladder logic
- Fast feedback on programming

In students' responses to the question "This tool could be improved by:" common themes were 1) wishing they could check out a unit to use outside of class; 2) desire for greater variety of inputs and outputs; and 3) desire for more units to be available. The comments are below:

- Better connection to computer to lessen resets
- It works good already. I don't see a need to improve.
- Having a virtual PLC to test homework @ home.
- Sometimes micrologix can be very buggy in class which is annoying.
- Better conection cables between PLC and the computer.
- More variety of outputs, not just lights
- Making it more available at a service desk one week before the exam.
- Giving students their own to take home!
- Having the PLC more available. Either through check out units or an online, virtual PLC model where programs can be checked.
- Updating the equipment w/more outputs
- Finding a way that portable PLC's can be taken home by students so that HW can be done & tested easily at home.
- different types of PLCs
- different inputs and outputs. more push buttons.
- More time
- Having it more available after class.
- Increasing versatility or perhaps take user inputs.
- more lights and inputs
- Designing a program that can act as a PLC so you can test your RSLogic out of class.
- This tool is great. I just wish there was a program that would display successful outputs and inputs from RSLinx at home. It is hard to do homework because there is no way to test our program. It basically becomes a guessing game and makes it hard to study for the exam.

- Having one for everybody.
- Having access to the Portable PLC outside of class.
- Working more often
- Integrating it more with the lesson so that it's not just a chunk at the end.
- This tool is a sufficient form of instruction.
- I think they are sufficient.
- Visualizing a bigger PLC, in a smaller version.
- getting to use it a few more times, maybe give the students a situation and see what solution they come up with.
- You need more PLC units. I had a group of three and could never work with the PLC unit due to the fact we had to cram around one computer.
- Providing us with the opportunity to wire portable PLCs in class, if time allows.
- Having students produce more advanced program designs.
- being a little smaller and more portable. a smaller version running of the usb output power.
- This tool is a sufficient method of instruction.
- More exercises
- Just have a straight USB to USB connection and lose the serial port + USB to serial adapter. Maybe just have the switches better and make sure things are running smooth. Some of the boxes didn't work all the time.
- Using them on homework assignments outside of class
- I would recommend more time be spent with the PLC in class time and less on the subject matter we spend the last couple of weeks in class discussing.
- Being able to control a robot. Using motors was great but I'd like to see something using limit switches on a conveyor or working with some other type of programmable machine with the PLC
- Probably just spending more time in class with it
- Better examples to use with the PLCs would be helpful.
- Allowing us to see the wiring of the PLC itself.
- Better construction, some switches/ buttons not working
- Having enough for the whole class, or at least enough for each pair to have their own.
- Adding more questions for all topics covered in this class
- Using it.
- It is awesome, no improvements needed.
- making it smaller
- More use during lecture
- This tool could be improved by allowing the program to be able to run and tested before downloading it to the PLC for further testing.
- Making a virtual PLC so that I can write and check my homework before I turn it it. This also helps me to visualize the homework like in lab.
- Going further in depth with explanations and descriptions to make learning easier.
- Having a more integrated classroom experience, where it is already programmed or the steps of programming it contribute to the discussion, or by removing it from the classroom and just using it in the lab.

- Having more time and practice using it (class time is too short!)
- Having more access to this, or an online version for use with homework would be great.

Conclusion and Future Directions

The evaluation responses suggest that the Portable PLC kits were well-received by students. Plans for the future include:

- Build more portable PLC kits so that a lower student-to-kit ratio can be achieved.
- Place some portable PLC kits on reserve in the library so that students can check them out as needed.
- Build special function modules that allow students to see how sensors and switches are incorporated into real-life applications.
- Inspect the modules prior to the beginning of classes and make repairs as needed.
- Continue designing homework assignments and in-class exercises that incorporate use of the PLC kits to enhance experiential learning.

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