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RET: Programmable Logic Controller and Fischertechnik System for High School Digital Electronics Education

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Abstract

High school digital electronics courses typically cover the following topics: 1) logic gates and Boolean algebra; 2) sequential circuits such as flip-flops, latches, counters, and shift registers; 3) memory; 4) programming and interfacing in microcontrollers; and 5) digital systems design for real-world problems. These topics are typically taught through a combination of lectures, demonstrations, and hands-on activities. High school courses that teach industrial controllers, such as programmable logic controllers (PLC), are relatively uncommon, even though controllers can be used in teaching all the topics listed above. This is due to the high cost of equipment and training and to faculty lacking expertise in PLC.

In this paper, we describe an NSF Research Experiences for Teachers (RET) project that involved development and evaluation of student activities utilizing a working model of an automated system. These materials were implemented within six classes of 15-20 students each. Preliminary results show that most of the students are not familiar with ladder logic and programmable logic controllers. However, they are interested in learning more about these topics and how they can be applied in automated system design.

Future work includes delivering the lesson to additional students; finding out what works and what does not work; acquiring more sensors, PLCs, and Fischertechnik building blocks to accommodate more students; building different types of automated systems to teach different PLC instructions; integrating a wireless module to connect the system to a mobile phone for remote access and control; and introducing machine learning into the curriculum.

Motivation

A programmable logic controller (PLC) is a solid-state control system with a user-programmable memory that can read input conditions and set output conditions to control a machine or process. PLCs are programmed using ladder logic (LL). LL is being used by manufacturing companies to automate systems. Companies in the food and beverage, automotive, shipping, and manufacturing industries are using LL and PLCs to meet demand during staffing shortages [1-2]. Many colleges and universities offer associate degrees, bachelor's degrees, and even master's degrees in industrial automation or related fields. These programs typically include coursework in PLCs. Recently, there is a trend to teach PLC Level I to career ready students at the high school level [3]. The Texas Education Agency has developed a syllabus guideline for programmable logic controller I education in high school grade 10 to 12 level [4].

LL and PLCs are specialized skill sets that are sought out by competitive employers such as Beckhoff and Rockwell. Persons entering the workforce with a working understanding and knowledge of PLCs are highly sought after. In Texas, LL & PLC skills are recognized through the PLC Technician Certification [5] and the NOCTI Robotics & Automation Certification [6], which require a minimal education of a high school diploma. Teaching PLC & LL at the high school level would provide an informed specialized skill set for students seeking to begin technical careers after graduation. The current staffing storage is amplified by the lack of technical skilled labor.

Over the years, researchers have employed different instructional techniques for PLC education. Examples of work include (1) animation to teach PLC image table and interface [7] and (2) intelligent tutoring system to teach Timer and Counter instructions of PLC [8]. One recent development, PortablePLC, integrates PLC, sensors and automated systems built upon Fischertechnik modules and fits everything into a small carrying case [9-11]. PortablePLC has been evaluated in the classroom to provide hands on and experiential learning during lectures and student evaluations have been positive. Fischertechnik modules are construction kits produced by Fischertechnik GmbH in Waldachtal, Germany. The kits can be used to build models of industrial systems such as machining systems, sorting lines, and robots [12].

Scholars at the high school level spend four years exploring future career choices. Many students find are tactile learners—they learn best through hands-on experiences. The Allen-Bradley PLC and Fischertechnik systems provide advanced learning tools for career and technical education. Among 16- to 24-year-olds, 41.9% of recent high school dropouts were working or looking for work, lower than the labor force participation rate of 69.2% for recent high school graduates not enrolled in college [13]. Exposing students to higher level technical skills during their early years increases economic opportunities for low-income households.

Physical System Design

A model of a robot welding system was built using a PLC, Fischertechnik modules, relays, power supply, DC to DC voltage regulator, and breadboard. Figure 1 shows the overall system, components involved, and their physical locations. The Smart Welding Robot is comprised of an Allen-Bradley Micrologix 1000 PLC connected directly to a 24V DC power supply. The DC-to-DC voltage regulator reduces the power output in conjunction with a terminal relay so that the Fischertechnik system does not become overloaded, while providing sufficient power for operation to the PLC. There are two switches to activate the welding simulator. The switch in the lower right activates the automated welding simulator and the switch in the upper left stops the system.

Figure 2(a) shows the overall system. Figure 2(b) shows the large circular gears (driven) are perpendicular to the worm gear (driver); the gearbox and motor work in tandem to activate the system. Figure 2(c) shows the breadboard that acts as the junction box for all the I/O interface wiring. The Welding Robot system is driven by a Ladder Logic program. The system is composed of six major devices. The Bill of Materials for the PLC controlled welding robot system includes Allen-Bradley PLC (1), DC Power Supply (1), Terminal Relay (1), Input/Output 30-line bread board (1), DC-to-DC Converter (1), and a Fischertechnik Electronics/Profi/ Dynamic/Advanced STEM kit.

Schematic diagram & wiring

A relay is employed to allow the motor to change the direction of rotation so that the robot arm can move clockwise and counterclockwise. A voltage regulator (120VAD to 24VDC) is used to convert the 120VAC outlet to 24VDC needed for PLC. Also, a DC-to-DC voltage regulator is used to further reduce the voltage to the 9VDC needed by the Fischertechnik I/O devices and relay. The breadboard is used to facilitate the wiring task.

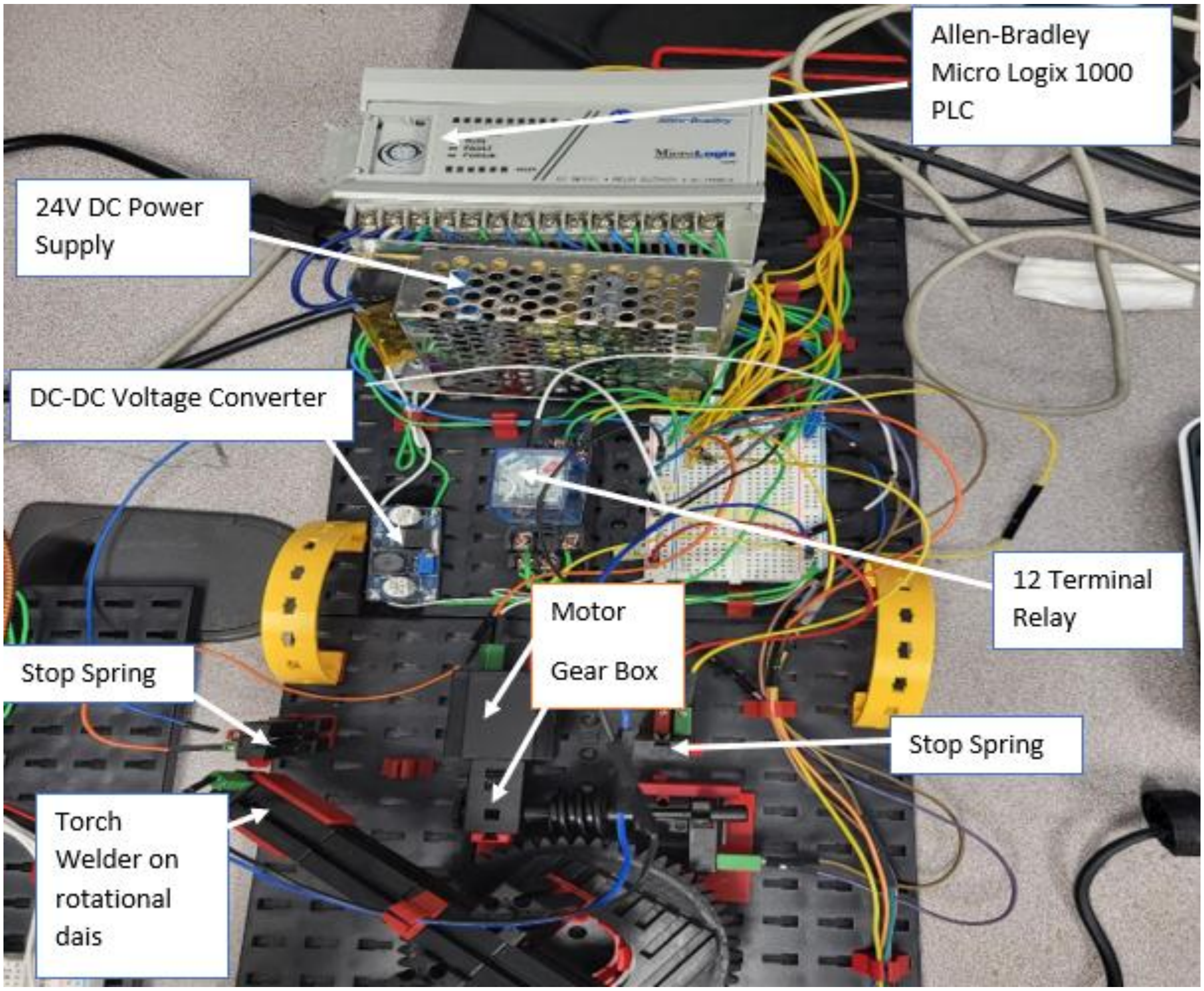
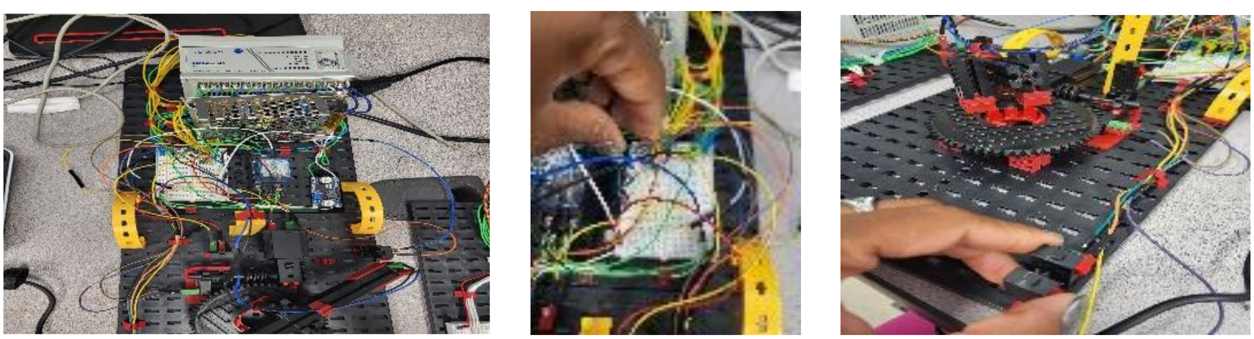


Figure 1. PLC- based Welding Robot System.



(a) (b) (c)

Figure 2. (a) Overall System, (b) Gear and gearbox, (c) Breadboard used for wiring.

Student activity

Students constructed and wired a small-scale Welding Robot model. They were introduced to Ladder Logic (LL) programming. The Fischertechnik Electronics module was used to provide hands-on design and visual representation for correctly written automation language. Students focused on learning and understanding Ladder Logic language for Programmable Logic Control (PLC).

The lesson was taught as part of a high school course entitled *Robotics I and Digital Electronics*. Learning objectives addressed include:

- explain the importance of digital control devices, including microcontrollers in controlling mechanical systems
- identify everyday products that use microcontrollers such as robots, garage door openers, traffic lights, and home thermostats
- demonstrate an understanding of the use of flowcharts as graphical organizers by technicians, computer programmers, engineers, and other professionals and the benefits of various flowcharting techniques.

Evaluation

As students had no previous exposure to Programmable Logic Controllers, the evaluation consisted of a post-test only. Questions included:

1. Define and explain Ladder Logic.
2. What is a PLC used for?
3. Draw the symbol representation for Examine If Open
4. Draw the symbol representation for Examine if Closed
5. What is a PLC used for? Name three industries that use PLCs.
6. How is Ladder Logic similar to Data Logic?
7. How is Ladder Logic different from Data Logic?

Results

The lesson was evaluated by 14 students. Scores ranged from 3 to 7 (out of 7 possible correct answers). The median score was 5 and the mean was 5.07.

Figure 3. Students using system.

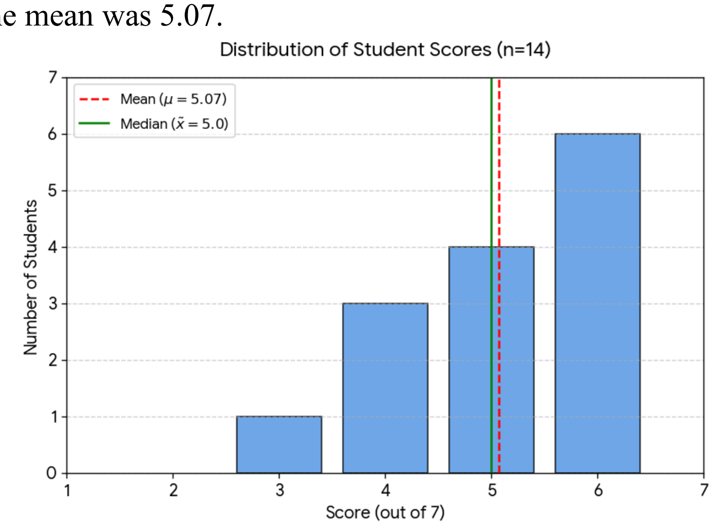


Figure 4. Visual summary of evaluation results.

Students were asked a reflection question: *What are your thoughts on learning about Programmable Logic Controllers and Ladder Logic?* Responses included:

- My thoughts are that they are very useful to create effective systems at solving problems and completing tasks especially if things need to be done precisely and in order.
- I think it is a very fascinating topic that will definitely equip me with valuable skills.
- I gained a further understanding on how to visually decode a documented wiring.
- I know they are both used to create and control circuits and how to modify them easily.
- It's a great beginner's topic to know for this pathway.
- I definitely need to spend more time learning it.
- I need to learn more to have a better understanding of this subject.
- I think it is important to learn it because I want to start coding robots
- I think that learning about programmable logic controllers and ladder logic is a very useful skill we should learn and it will help us in the future.
- I'm interested to learn more about this subject.

These responses suggest that students thought learning about PLCs and ladder logic was interesting and would be beneficial for their future careers.

Lesson Learned/Future Improvements

Between supply chain challenges affecting availability of parts and school districts' stringent purchase order guidelines, meeting delivery deadlines can be challenging. It is important to start the ordering process as soon as possible. The lesson will be added to the "STEAM Your Future" mobile unit that provides STEM learning to public education students in a camp format at no cost.

Acknowledgements

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