# MAKER: Smart Lighting Module for Teaching High School Science and Engineering Students about Programmable Logic Controllers

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# MAKER: Smart Lighting Module for Teaching High School Science and Engineering Students about Programmable Logic Controllers

This paper describes the design, construction, and evaluation of an instructional module for 9th-12th grade science and engineering students on the use of a Programmable Logic Controller and Ladder Logic Programming to save energy in a "Smart Room." This module was created as a result of the author's attending a Summer Research Experiences for Teachers program. The instructional module includes lecture and activity components. The lecture component covers the history of PLCs, how they work, and how to use Ladder Logic Programming to control input and output components in a "Smart Room". The lecture also provides a brief introduction to Boolean Logic as it is used for Ladder Logic programming. The activity component includes hands-on examples of how to design and build energy saving devices into a room lighting system, including use of a PLC to manage the room's lighting. Three evaluations are built into the lesson: pre-assessment, post-assessment and student evaluation of the lesson as a whole. The module was piloted in four high school engineering classes. Students worked in teams to build and successfully test AOI Logic and then build and test input/output controls for a "Smart Room" lighting system controlled by a PLC. Test results from the pre- and post-tests indicated that a high level of learning was achieved. In addition, the students all enjoyed the hands on experience.

## Motivation

Conserving energy at home and at work has become increasingly important. In the best case scenario, commercial buildings have one thermostat and one light switch per room. In most residential structures and small commercial buildings, several rooms are controlled by one input. However, any given room is likely to be occupied far less than fifty percent of the time. The lesson addresses the cost of lighting a room and shows that "programmable logic" can be used to adapt room lighting patterns as usage patterns change without a need for reprogramming.

The first smart room was designed in 1991 at MIT. The initiative has grown ever since then. Today companies claim to be manufacturers of "Smart Buildings"; the bulk of their efforts center on insulation and HVAC, and using appliances with good SEER ratings. Recently, industry one-upmanship has led to programmable devices such as programmable thermostats and room zoning in HVAC systems. There are also tank-less water heaters for bathrooms, laundry rooms, and kitchens. For home lighting, there are motion sensors to control outside lighting; some devices use timers to control lighting, especially seasonal lighting such as Christmas lights.

## Engineering Connection

A Programmable Logic Controller (PLC) is a digital computer used for automation of typically industrial electromechanical processes, such as controlling machinery on an assembly line processes, controlling amusement rides, and controlling automated car washes. PLC are designed for multiple arrangements of digital and analog inputs and outputs, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact.

Programs to control a PLC machine operation are typically stored in battery-backed-up storage or non-volatile memory.

As energy conservation becomes more important, ways to create better smart rooms is becoming more of a focus. Building construction is already addressing insulation and better HVAC systems and controls. Tank-less hot water heaters are being used in new and retrofit construction. Appliances are being built with better SEER ratings. To date a unified approach to control room lighting is still not solved.

**Lesson Title: Using PLC to Control Lighting in a "Smart Room"**

**Introduction:** This project will describe the design, construction, and evaluation of an instructional module for 9th-12th grade students in a science or engineering class. The module consists of a lecture with hands on activities to help students understand Boolean Logic. It will introduce the PLC and Ladder logic programming.

**Learning Objectives:** After this lesson the student should be able to (a) describe what a Programmable Logic Controller is (b) understand basic AOI Boolean Logic (c) be able to write a simple Ladder Logic program.

**Administer: Pre-Test (Appendix A)**

**Concepts for Teachers:**

The first PLC was introduced in the late 1960s. The first commercial and successful Programmable Logic Controller was built by Modicon Corp. as a replacer part for General Motors. Originally, it was a machine with thousands of parts, but in the late '70's with the advancement of solid state devices the PLC''s role was greatly enhanced permitting it to evolve from simple relays to the sophisticated system as it is today.

The major components of the PLC are a Power Supply, Inputs, Outputs, and a Processor Programming Device.
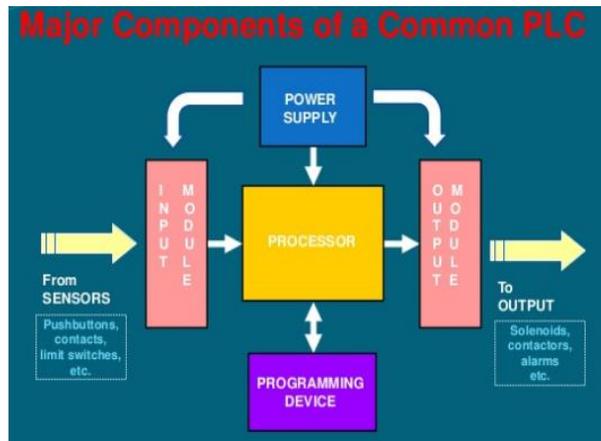


Figure 1. Major Components of a PLC

**Power Supply**

Provides the voltage to run the primary PLC components.

**I/O Modules**

Provide signal conversion and isolation between the internal logic level signals inside the PLC and the field's high level signal.

**Processor**

Provides intelligence to command and govern the activities of the entire PLC system.

**Programming Device**

Used to enter the desired program that will determine the sequence of operation and control of process equipment or driven machine.

**The PLC performs the following sequence of steps before running the program**
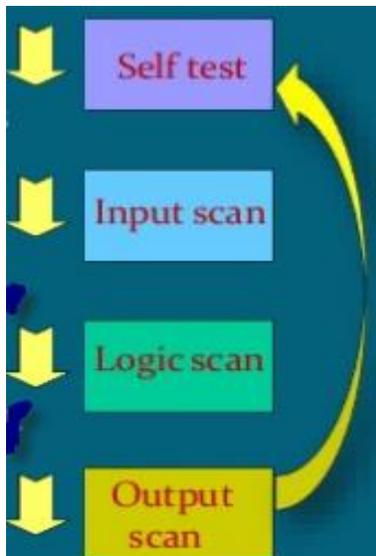


1. **Self-test:** Testing of its own hardware and software for faults.
2. **Input scan:** If there are no problems, PLC will copy all the inputs and copy their values into memory
3. **Logic solve/scan:** Using inputs, the ladder logic program is solved once and outputs are updated.
4. **Output scan:** While solving logic the output values are updated only in the memory, when the ladder logic scan is done the outputs will be updated in the memory.

PLC programming languages include Ladder Logic, Functional Block Diagrams, Sequential Function Chart, and Boolean Mnemonics. Ladder logic is the oldest programming language for the PLC. It is well suited for combinational logic. The main ladder logic symbols are:
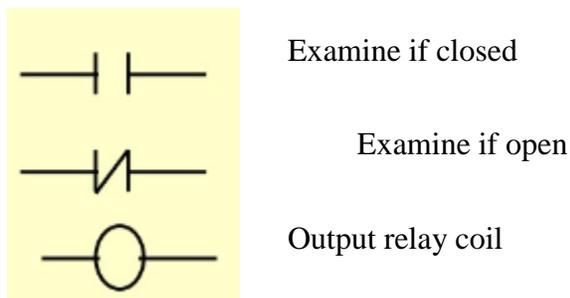


Examine if closed

Examine if open

Output relay coil
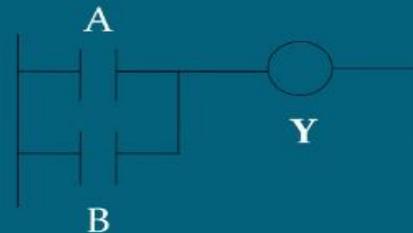
**Please note that the Examine A and Examine B inputs function the same as AOI Digital Logic**

When programming with a Ladder Logic you will be programming the "rungs" of the ladder. The program will read each rung from left to right. It will then advance down to the next rung and do the same. The state of the final rung will control the output devices.

It is important to recognize that the PLC is a microprocessor. The inputs are real world devices as are the outputs. One way to vision the PLC is to imagine that the PLC acts as electronic contacts of a relay. They function as either open or closed. If the switch is closed and the ladder logic program says "examine if closed" then the output side of the PLC will close the contact and energize the output device.

Some of the advantages of the PLC are: Reliability, Flexibility in programming, cost effectiveness, small physical size, high speed operation, ability to communicate with computers and the web, ease of maintenance, energy saving.

**Vocabulary / Definitions**

| Word | Definition |
|------|-----------|
| Current | Current is actually the flow of electrons or conventionally speaking the positive charge in a direction opposite to that of electrons |
| Switch | A mechanical or electronic device that opens or closes an electrical circuit. It has many variations. |
| Infrared light | Electromagnetic radiation with wavelengths longer than visible **light** but shorter than radio waves. |
| Diaphragm Pressure Sensor | Will give a measure of the gauge pressure in a system. One side is open to the atmosphere and the other side senses the pressure. |

| Word | Definition |
|---|---|
| Series circuit | A **series circuit** is a closed **circuit** in which the current follows one path. |
| Parallel circuit | A parallel **circuit** is where the **circuit** is divided into two or more paths. |
| Memory | The **memory** cell is the fundamental building block of computer **memory**. The **memory** cell is an electronic **circuit** that stores one bit of binary information and it must be set to store a logic 1 (high voltage level) and reset to store a logic 0 (low voltage level). |
| Voltage | A type of "pressure" that drives electrical charges through a circuit. |
| Processor | A part of a **computer**, such as the central processing unit, that performs calculations or other manipulations of data. A program that translates another program into a form acceptable by the **computer** being used. |
| Input | **Input** can take a variety of forms, from commands you enter from the keyboard to data from another **computer** or device. A device that feeds data into a **computer**, such as a keyboard or mouse, is called an **input** device. |
| Output | An **output** device is any piece of **computer** hardware item used to communicate the results of data processing carried out by an information processing system (such as a **computer**) which converts the electronically generated information into human-readable form. |
| Shaft Encoder | A **shaft encoder**, is an electro-mechanical device that converts the angular position or motion of a **shaft** or axle to an analog or digital code. |
| Normally Open Spring Return | A **spring return** (momentary) **switch** returns its contacts to their original position ... "**Normally open**" |
| Normally Closed Spring Return | A **spring return** (momentary) **switch** returns its contacts to their original position ... "**Normally Closed**" |
| Relay | A **relay** is an electrically operated switch. Many relays use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as solid-state relays. Relays are used where it is necessary to control a circuit by a separate low-power signal. |
| Counter | In digital logic and computing, a **counter** is a device which stores (and sometimes displays) the number of times a particular event or process has occurred, often in relationship to a clock signal. The most common type is a sequential digital logic circuit with an input line called the "clock" and multiple output lines. |

**Warm up activity:**

1.    Using the materials provided create a test box and wire it to the PLC.
- 2  Lights
- 2  SPST switches
- 2  NOSR Pushbuttons
- Pre-drilled box
- 1 Lot   Wire
- 1 Lot   Wire color tape



Write your program
using the Click
software and save it.



Solder and check your
devices
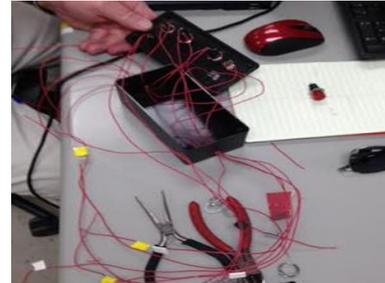


Wire the pushbuttons for
Parallel and switches for
Series
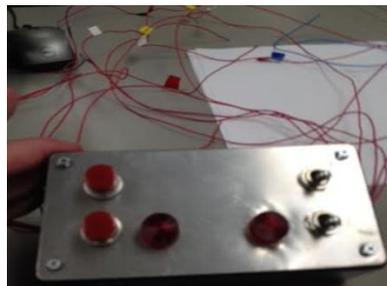


Mate the test box to the PLC
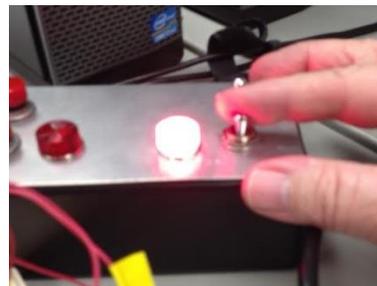


Test your work

Rung 1 is a series command or an AOI "And" gate equivalent
Rung 2 is a parallel command or an AOI "Or" gate equivalent
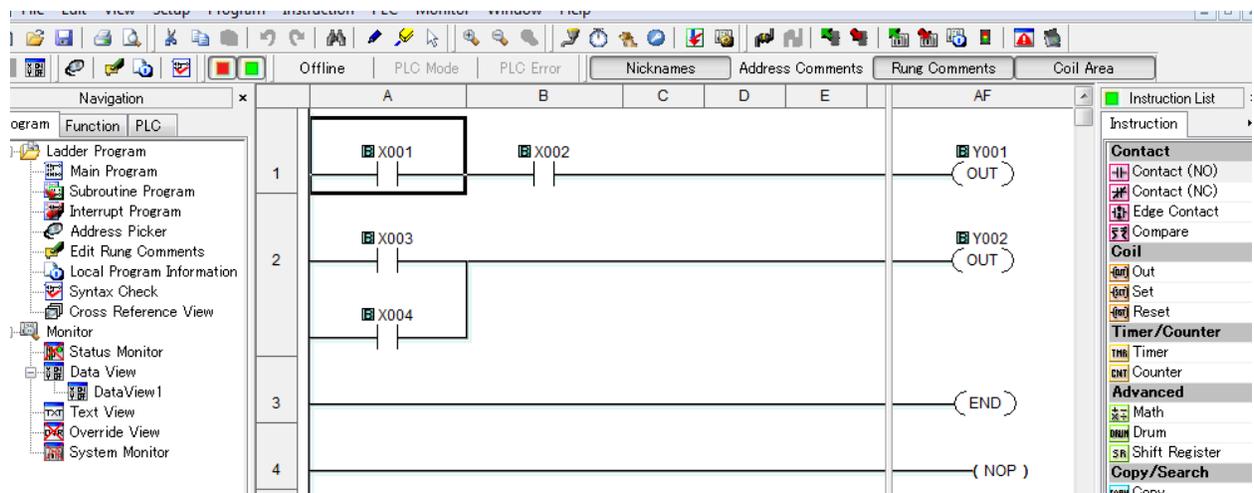
Use the click software to write a ladder logic program

The total cost was $23.50 per box. This does not include the cost of the PLC and the step down transformer.

## AOI Logic Box Video

https://youtu.be/iuSEKke4pzw
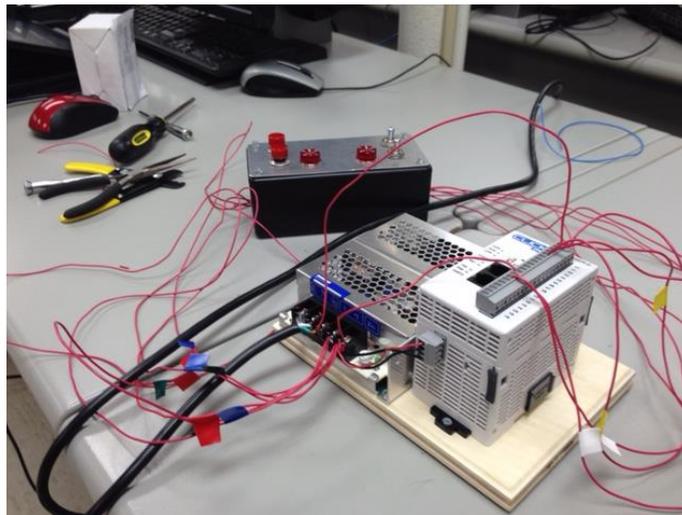
**Activity Title: PLC controlling lighting in a "Smart Room"**

**Needed on hand materials to build the test system:**

Each group needs:

- Safety Glasses
- Wire Cutters
- Small Screw Driver
- Wire strippers
- Small Desk Lamp

**Materials to share with the entire class:   (Groups of four)**

Each group needs:

- Click PLC
- 24VDC Power Supply
- Small Desk Lamp
- 2ea v120VAC Coil 24VDC contacts relay
- Wireless Motion Detector  & Transmitter
- Motion Receiver
- 12VDC Light Sensor Power Supply
- Light Sensitive Switch
- Clapper Light Switch
- Wire 22ga
- Wire 12ga
- 6"x12"x1/4" Mounting Board

Other materials

| Product Number | Product/URL | Units | Cost per unit |
|---|---|---|---|
| MK 125 Velleman (Fry's Electronics) | Light sensitive switch | 1 | = $7.99 |
| ID-318 Skylink Home (Fry's Elect) | Wireless Motion Sensor | 1 | = $8.90 |
| Desk Lamp WalMart | Small desk lamp 40w | 1 | = $6.12 |

| Product Number | Product/URL | Units | Cost per unit |
|---|---|---|---|
| IR-318 Skylink Home (Fry's Elect) | Wireless Motion Receiver | 1 | = $8.17 |
| The Clapper | Sound Sensitive Switch | 1 | = $ 18.87 |
| 12VDC Power | 12 VDC PWR Supply | 1 | = $16.65 |
| 4 FE 15 (WW Grainger) | 120 VAC Relay | 2 | = $12.20 = $24.40 |
| 6C898 (WW Grainger) | Socket | 2 | = $5.29 = $10.58 |
| 6" X 12" X 14" | Mounting Board | 1 | = $3.27 |
| C0-00DR-D | Click PLC | 1 | = $68.00 |
| | 24 VDC Power Supply | 1 | = $30.00 |
| | 12 gage Wire 10' BLK &v10' White | 20' | = $ 3.40 |

Total          $198.18

**Procedure:**

**Time Planning:**

- Schedule this activity to take about 4 to 5, 90 minute class periods spread over a week. The first day of the project includes an introduction and assignment of the design project, and the last day is for student presentations. The three periods between are class time for student groups to work on the project. If the class time for students to work on the project is instead assigned as homework, the class time required for this activity can be significantly reduced to ~1-2 class periods.

**Before the Activity:**

- Assuming a group size of four students, determine how many engineering design groups you will have in each class. Then make copies of the activity and each deliverable.
- Become familiar with the types of failure that the students will generate.

**Safety Issues:**

- Before starting go over the safety rules!! And your expectations.
- Everyone must wear safety glasses during the lab!!

**Activity Extensions:**

- To give this activity more of an engineering design project context, have groups divide up responsibilities and assign roles to each group member such as project manager, project engineer, cost engineer, design engineer, etc. Guide them through the engineering design process and have students compose a formal report to turn in for grading.

**Activity Scaling:**

- For lower grades, or for students who struggle with engineering, provide a wiring diagram that the student can use.
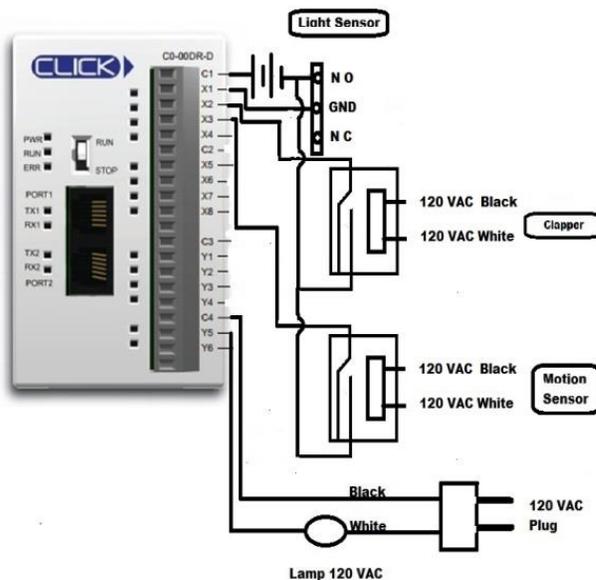


**Image 1**

**Image file:** PLC Wiring Diagram.jpeg

**ADA Description:** The picture shows a detailed wiring diagram for the project.

**Source/Rights:** Bill Heeter, Author

**Caption:** Wiring Diagram of the PLC for the "Smart Room"

**Step by Step:**

- Before you begin lay out your design and make sure you have everything you will need including safety glasses.
- Mount the 120 VAC relay sockets to the board
- Mount the MR-318 Skylink Receiver to the board
- Connect the line voltage and neutral to the MR-318 Skylink Receiver

    Connect the Red MR-318 Receiver wire to one of the 120VAC coil legs on the socket
- Mount the light sensor to the board
- Place 2 Velcro Strips on the board

Time to begin wiring:  Be sure to do one sensor at a time.  Go slow and double check everything.


Wiring Lamp

- Connect one leg of the light to 120 VAC power the other will go to the PLC output  Y-1.
- Connect 120VAC to C-4.


Wiring the Light Sensor

- Plug the 12VDC power supply into the board
- Wire the COM to C-1
- Wire the N-O contact to X-1


Wiring Motion Sensor MR-318

- Wire Line and Power voltage into an extension cord to be plugged into the multi-tap.
- Wire the line voltage to one side of a coil wire the red chord to the other side of the coil
- Wire the common contact on the switch to C-1
- Wire the N-O contact on the switch to X-2


Wiring the Clapper

- Create an extension cord that one end plugs into the Clapper outlet receptacle
- Wire the Line and Power Voltage onto each side of the second relay coil.
- Wire the common terminal to C-1
- Wire the N-O contact on the switch to X-3
- Write the Click software Program
- Test the program
- Down Load the Program
- Run and verify the program

**PLC controlling inputs and outputs of a "Smart Room" Video**

https://youtu.be/oI2TjQfHZTE
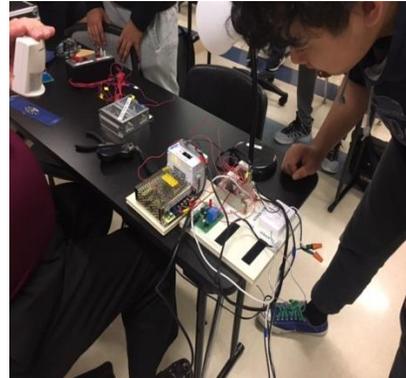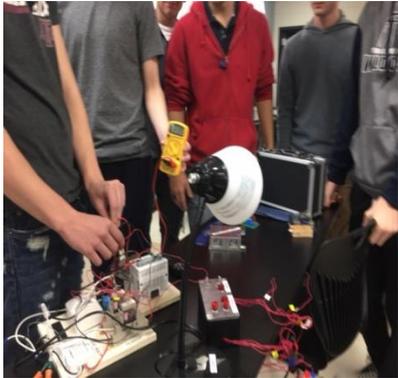


**Administer Post-Test (Appendix B) and Student Evaluation**

**Results & Conclusions:**
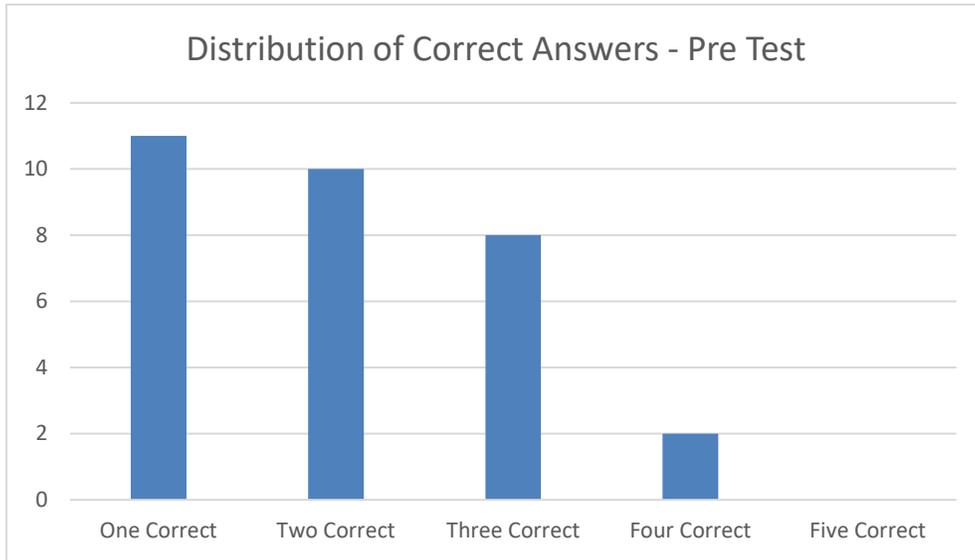


Pre-Test Assessment- Out of a total of 50 participants, only 31 were able to answer at least one question correctly. The students were instructed to skip questions they did not know, thereby eliminating potential skewing of baseline knowledge. Based on this data, the average percentage correct for each student, including students who did not answer any of the questions, was 25.2% (63 correct answers out of 250 possible).
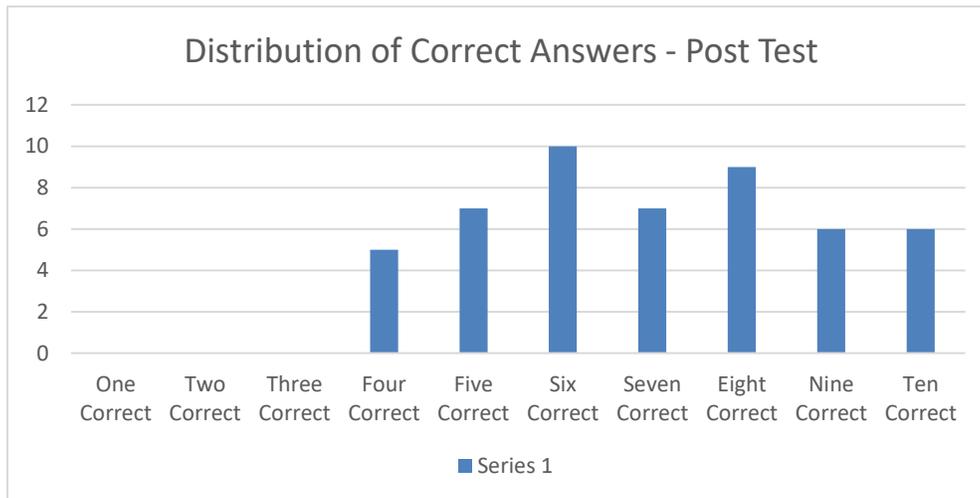
Post-Test Assessment- Out of a total of 50 participants, all participants were able to answer at least four questions correctly. This assessment included the five original pre-test assessment questions. Based on this data, the average percentage correct for each student, was 70% (350 correct answers out of 500 possible).
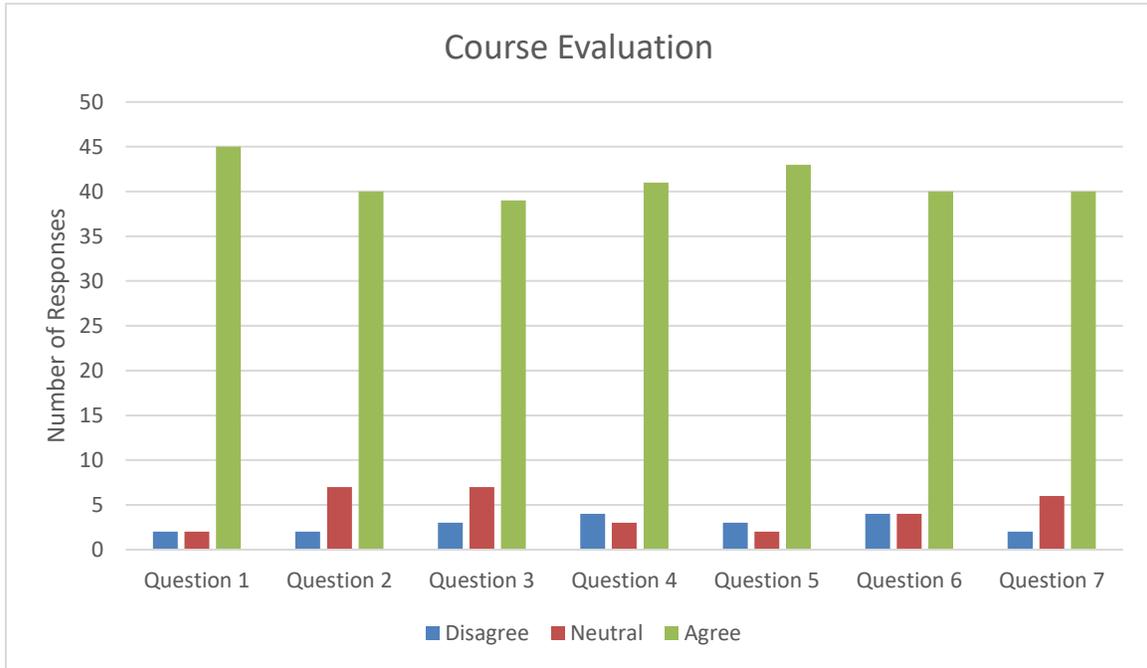


The course evaluation questionnaire consisted of seven Likert scale questions. Students were asked to read each question and rate whether they agreed or disagreed (1-Strongly Disagree – 10 Strongly Agree). *Analysis of this data assumes that ratings of 5 and 6 are neutral and do not indicate strong feelings one way or the other. Percentages have been rounded to the nearest integer.

Question 1: I would like to have more lessons like this.

| Disagree (1-4) | Neutral (5-6) | Agree (7-10) |
|---|---|---|
| 2 | 2 | 45 |

*Analysis*: Of the 49 responses received, 92% agreed that they would like more lessons like this.

Question 2: I learned a lot about PLC and how they work.

| Disagree (1-4) | Neutral (5-6) | Agree (7-10) |
|---|---|---|
| 2 | 7 | 40 |

*Analysis*: Of the 49 responses received, 82% agreed that they learned a lot about PLC and how they work.

Question 3:  The lesson was easy to understand.

| Disagree (1-4) | Neutral (5-6) | Agree (7-10) |
| --- | --- | --- |
| 3 | 7 | 39 |

*Analysis*: Of the 49 responses received, 80% agreed that the lesson was easy to understand.

Question 4: The lab was challenging, yet easy to complete.

| Disagree (1-4) | Neutral (5-6) | Agree (7-10) |
| --- | --- | --- |
| 4 | 3 | 41 |

*Analysis*: Of the 48 responses received, 85% agreed that the lab was challenging, yet easy to complete.

Question 5: The hands on experience helped me better understand the use of PLC.

| Disagree (1-4) | Neutral (5-6) | Agree (7-10) |
| --- | --- | --- |
| 3 | 2 | 43 |

*Analysis*: Of the 48 responses received, 90% agreed that the hands on experience helped them better understand the use of PLC.

Question 6: The Pre- and Post- Tests helped to confirm that I had learned from this lesson.

| Disagree (1-4) | Neutral (5-6) | Agree (7-10) |
| --- | --- | --- |
| 4 | 4 | 40 |

*Analysis*: Of the 48 responses received, 83% agreed that The Pre- and Post- Tests helped to confirm that they had learned from this lesson.

Question 7:  Using Teach Engineering was a good format for future lessons.

| Disagree (1-4) | Neutral (5-6) | Agree (7-10) |
| --- | --- | --- |
| 2 | 6 | 40 |

*Analysis*: Of the 48 responses received, 83% agreed that using Teach Engineering was a good format for future lessons.

**Acknowledgements**

**References:**

- By The original uploader was Dailynetworks at English Wikipedia - Transferred from en.wikipedia to Commons., Public Domain, https://commons.wikimedia.org/w/index.php?curid=2378719
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- Chun, S. Y., & Lee, C. (2015, May 28). Applications of Human Motion Tracking: Smart Lighting Control. Retrieved July 1, 2016.

**Appendix (A)**

**PLC Pre-Test**

This is a test to see your existing knowledge of PLC

1. The term PLC stands for?
   \_\_\_\_\_ Personal Logic Computer
   \_\_\_\_\_ Programmable Logic Computer
   \_\_\_\_\_ Programmable Logic Controller
   \_\_\_\_\_ Personal Logic Controller

2. Decide whether each statement is true or false:

   A transistor output channel from a PLC: i= is used only for DC switching  ii= is isolated from the output load by an optocoupler
   \_\_\_\_\_ i (T) ii (T)
   \_\_\_\_\_ i (T) ii (F)
   \_\_\_\_\_ i (F) ii (T)
   \_\_\_\_\_ i (F) ii (F)

3. A diaphragm pressure sensor is required to give a measure of the gauge pressure in a system.  Such a sensor will need to have a diaphragm with:
   \_\_\_\_\_ A vacuum on one side
   \_\_\_\_\_ One side open to the atmosphere
   \_\_\_\_\_ The pressure applied to both sides
   \_\_\_\_\_ A controlled adjustable pressure applied to one side

4. The change in resistance of an electrical resistance strain gauge with a factor of 2.0 and a resistance of 100 ohms when subject to a strain of .001 is:
   \_\_\_\_\_ .0002 ohms
   \_\_\_\_\_ .002 ohms
   \_\_\_\_\_ .02 ohms
   \_\_\_\_\_ .2 ohms

5. An incremental shaft encoder gives an output that is a direct measure of

_____ The diameter of the shaft
_____ The change in the diameter of the shaft
_____ The change in the angular position of the shaft
_____ The absolute angular position of the shaft

**Appendix (B)**

**PLC Post-Test**

This is a test to see your gained knowledge of PLC

1. --[\]-- Identify this ladder logic symbol
   _____ Examine if open
   _____ Examine if closed
   _____ Stop do not cross
   _____ Relay is open

2. --[ ]-- Identify this ladder logic symbol
   _____ Examine if open
   _____ Examine if closed
   _____ Cross
   _____ Relay is open

3. –( )-- Identify this ladder logic symbol
   _____ Input Control
   _____ Examine if closed
   _____ Out put Device
   _____ Insert text

4. Identify this ladder logic statement
   -----[ ]-----[ ]------( )
   _____ Examine twice
   _____ An "Or" statement
   _____ Start or Stop
   _____ A series statement

5. Identify this ladder logic statement
   ```
   |----[ ]----|
   |           |-----------( )
   |----[ ]----|
   ```
   _____ An "And" statement
   _____ Examine twice
   _____ Start or Stop
   _____ A parallel statement

6. The term PLC stands for?
   _____ Personal Logic Computer

_____ Programmable Logic Computer
_____ Programmable Logic Controller
_____ Personal Logic Controller

7. Decide whether each statement is true or false:

A transistor output channel from a PLC: i= is used only for DC switching  ii= is isolated from the output load by an optocoupler
_____ i (T) ii (T)
_____ i (T) ii (F)
_____ i (F) ii (T)
_____ i (F) ii (F)


8. A diaphragm pressure sensor is required to give a measure of the gauge pressure in a system.  Such a sensor will need to have a diaphragm with:
_____ A vacuum on one side
_____ One side open to the atmosphere
_____ The pressure applied to both sides
_____ A controlled adjustable pressure applied to one side

9. The change in resistance of an electrical resistance strain gauge with a factor of 2.0 and a resistance of 100 ohms when subject to a strain of .001 is:
_____ .0002 ohms
_____ .002 ohms
_____ .02 ohms
_____ .2 ohms

10.        An incremental shaft encoder gives an output that is a direct measure of
_____ The diameter of the shaft
_____ The change in the diameter of the shaft
_____ The change in the angular position of the shaft
_____ The absolute angular position of the shaft