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Teaching PLCs using the Kolb Learning Cycle

Abstract

This work describes an integral approach in teaching programmable logic controllers (PLCs) using the Kolb learning cycle. PLCs represent a module in a computer-integrated manufacturing course in two engineering programs at our institution. The two main learning objectives of this module are to demonstrate practical knowledge of PLCs by being able to program them and to develop a sufficient increase in problem solving skills using physical and PLC ladder logic when designing simple automation projects. Combined lecture and laboratory activities implementing the Kolb experiential learning cycle for the PLC module are addressed. The success of the module is assessed and evaluated through student performance tests in solving design problems using ladder logic and through student surveys. Results demonstrate an effective method for student learning when lectures and labs are integrated in a meaningful manner.

Introduction

In engineering education, depending on the material to be learned and the instructor’s style of teaching, a number of teaching and learning methodologies and their combinations are used. Since engineering is considered an applied discipline, many of the methods revolve around laboratory experiences as reinforcements to the engineering concepts taught during regular classroom-oriented sessions. Project-based learning and discovery-based learning are often used in engineering laboratories. However, integration of lectures and labs with their corresponding learning methods is difficult for a number of practical reasons.

Using the Kolb learning cycle students learn new concepts by following an activity pattern exemplified by the questions: “Why?,” “What?,” “How?,” and “What if?.” By repeating the cycle, students gain deeper understanding of the subject.

Programmable logic controllers (PLCs) are used frequently in many automation projects in industry. They are often an integral part of most computer-integrated manufacturing systems whether controlling individual machines or entire processes. Thus, it is important that students learn to use these devices to be able to design automated equipment or processes. Furthermore, students should gain knowledge that can easily be applied to PLCs of different types and manufacturers using different programming environments and different programming languages.

Previous Work

In 1976 and subsequently in 1984 Kolb\textsuperscript{1,2} presented a theory of learning styles and incorporated this theory into a theory of learning, “Kolb’s Experiential Learning Cycle.” According to Kolb\textsuperscript{2}, regardless of the learning style, people learn best if they follow this cycle consisting of four steps (axes): experiencing (concrete experience), watching (reflective observation), thinking/modeling (abstract conceptualization), and applying/doing (active experimentation). A set of activities exemplified by questions “Why?,” “What?,” “How?,” and “What if?” enable the learner to move...
between the cycle axes\(^2\), where the above questions correspond to quadrants of Kolb's cycle, from 1 to 4, respectively. Figure 1 depicts Kolb's learning cycle\(^5\) with activity sets for each quadrant\(^4,5\). By traversing the cycle in a clock-wise direction one learns by completing the cycle. Each additional cycle brings deeper knowledge to the learner.

![Diagram of Kolb's Learning Cycle](image)

Figure 1. Learning Activities of the Kolb Learning Cycle\(^4,5\)

Since its discovery, Kolb's learning cycle has been used in various engineering education programs. In 1993, Harb et al\(^3\) applied Kolb's learning cycle with the 4MAT system\(^3\) encompassing topics from four engineering disciplines, i.e. civil engineering, chemical engineering, construction management, and manufacturing engineering. In 1997, Sharp et al\(^6\) describes writing exercises within the framework of Kolb's cycle and 4MAT system to increase learning in engineering courses. Ortiz and Bachofen\(^7\) report that the use of Kolb's learning cycle
in aeronautical, mechanical and civil engineering programs reduces learning time (opposite Harb et al.) and improves students’ interest, class attendance and course completion. Wyrick and Hilsen applied Kolb’s cycle in an industrial engineering program spanning four courses and analyzing ten years of data. They report deep learning and warn faculty of lower-than-usual student course evaluations. Harding et al. describe use of Kolb’s cycle in a Materials and Process Selection course within their manufacturing engineering program. In 2009, Abdulwahed and Nagy implemented Kolb’s cycle in process control laboratory within a chemical engineering program.

Most of the engineering education research on Kolb’s cycle deals with implementations of this learning method in different engineering course environments. However, there seems to be little formal quantitative assessment/evaluation reported. Gains in content knowledge don’t seem to be significant, while “deep knowledge” is not measured quantitatively.

Curriculum Context

The activities described in Figure 1 are applied in a required computer-integrated manufacturing (CIM) course at our university in two engineering programs: the Industrial Engineering and the Bachelor of Science in Engineering with Specialization in Mechatronics. The CIM course is a senior-level design-based course dealing with modern technologies such as automation, digital controllers, programmable logical controllers (PLCs), computer-numerically controlled (CNC) machines, and robotics. The CIM laboratory curriculum includes hands-on experiences with simple digital controllers, PLCs, CNC mills, and robots. PLCs are industrial grade computers used extensively in automation. In this study, we concentrate on the PLC experience. Laboratory exercises are developed to enable students to learn and to enhance their problem-solving skills using familiar design situations.

PLC Module Description

Since the lectures and the experiments are integrated the module is described within the context of Kolb’s cycles. In general, for five weeks, students learn ladder logic (both physical and PLC), pneumatic and hydraulic circuits, switches and sensors in the classroom and in the laboratory. The course philosophy is such that ladder logic diagrams with simple inputs and outputs are used so to keep the diagrams and the designs independent of PLC types as much as possible. While the concepts are relatively simple, the design applications can be quite complicated and complex. There are four laboratory exercises. One exercise is used to enable students to effectively use the PLC graphical user interface and the PLC programming environment. The remaining three laboratory exercises represent the design problems of increasing difficulty. One homework assignment and two tests (a module test and a comprehensive final test) are implemented as learning tools and to evaluate the “deep learning” component of the PLC design skills.

Experimental Setups

There are two experimental setups used in the PLC module. The first setup is based on a commercially designed trainer, shown in figures 2 and 3, while the second setup of a miniature road intersection with traffic lights and road sensors (Figure 4) is developed in-house.
Figure 2. PLC Trainer using SLC 150

Figure 3. a) PLC Trainer Detail: Top - Solenoids Simulating Valves with a Motor Simulating a Pump; Middle - Piezoelectric Horn and a Thermostat; Bottom - Indicator Lights and Switches b) Top - A Motor with a Lead Screw and Limit Switches Simulating a Liquid Level Indicator; Middle – Relays; Bottom – Switches and Indicators
Before each laboratory exercise, the instructor demonstrated a possible working design to assure students that the laboratory hardware performed correctly, and that the given task is achievable.

**Cycle 1**

During the first two hours in the classroom, (first quadrant) the importance of being able to automate an industrial process was emphasized. Then, both theoretical and practical aspects of PLCs are explained. This gives a “big picture” of the topic. As second quadrant activities, elements of the physical ladder logic (switches, outputs, and relays) are discussed. Two rudimentary examples (turning on/off a light bulb and implementing a flashing light) are presented in detail. In the laboratory, as third quadrant activities, students are engaged in programming a PLC for the first time. They work individually.

In this first experiment, the design of a reversible DC motor, I/O wiring to the PLC, and the ladder logic program are given. The design problem with accompanying setup simulates a polishing operation that requires a polishing tool to move left and right many times. An automatic system including a motor with a lead screw connected to the tool, a START/STOP SPST switch, and two limit switches is prepared. An Allen-Bradley SLC 150 PLC is used as a controller. When the motor is running in the forward direction the tool is moving to the left. When the motor is running in reverse the tool is moving to the right. Students are to design and implement ladder logic control for this system for the I/O configuration described in Table 1. Figure 5 depicts the PLC ladder logic diagram to be implemented.
Table 1. I/O Configuration for Polishing Application

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>START/STOP (ST)</td>
<td>1</td>
</tr>
<tr>
<td>Left limit switch (LLS)</td>
<td>3</td>
</tr>
<tr>
<td>Right limit switch (RLS)</td>
<td>4</td>
</tr>
<tr>
<td>Motor Reverse (MR)</td>
<td>11</td>
</tr>
<tr>
<td>Motor Forward (MF)</td>
<td>12</td>
</tr>
</tbody>
</table>

To finish the cycle, after successfully completing the lab exercise, students write a short report on their experiences in the lab. They are asked to address questions such as “Was the lab hard?,” “What did you like/dislike about the lab?,” and “Where there any obstacles that you had to overcome in completing the assignment?.”

Cycle 2

During the second week, in the classroom, pneumatic and hydraulic circuits are introduced. The operating principles of valves are described using the audio/visual equipment. The advantages and disadvantages of each mode of actuation (pneumatic, hydraulic, and electrical) are justified and tabulated as a result of class discussion. Then, as a part of second quadrant activities, two more complex problems are solved on the board by the instructor (two flashing lights and starting three motors with time intervals). Then, another four problems are in turn projected on the board. Students are asked to form pairs or groups of three and solve these problems. After checking their work, the instructor would ask one group to present their solution. Then, the whole class would critique it. Some of the problems presented design modifications, while others involved complete designs.

In the lab, as a part of the third quadrant activities, students designed and implemented solutions to a typical discrete system. The application of timers was emphasized. Students worked in pairs. The model road intersection of Figure 4, as described in our previous work, was used. The
intersection includes two pairs of traffic lights and four inductive sensors capable of detecting the presence of cars at the intersection. A pair of traffic lights is controlled by parallel outputs from the PLC, i.e. there are three outputs per one set of traffic lights (one for green, one for yellow and one for red lights). The experiment set consists of three experiments. The first two experiments were implemented in the second week. Some students needed extra time to complete these two sets.

The first experiment dealt with a single set of traffic lights. Students were to implement their own designs in controlling the lights. The PLC should turn on the red traffic lights for 25 seconds, then the green traffic lights for 32 seconds, and finally the yellow traffic lights for 3 seconds.

In the second experiment, students were to design and implement a ladder logic program to control two sets of traffic lights used in a typical intersection where one street (the main street) is busier than the other (the side street). For the main street, the light sequence and the duration were the same as specified in the previous experiment. Students were to determine the traffic light behavior for the side street.

The cycle was finished in the classroom during the third week of the module. Students working in groups (the same groups as in the lab) solved a set of design problems. The instructor helped by working with individual groups when needed. The lab designs were also discussed.

**Cycle 3**

During the second class hour of week three, as first quadrant activities, a homework assignment was introduced, and some simple pneumatic and hydraulic design problems were solved by the instructor. One problem with filling/empting a tank was introduced (a similar problem was assigned as a homework assignment). Students solved this problem while working in groups.

In the laboratory, the third traffic experiment implementing sensors was assigned and completed. The green traffic lights of the main street are to be on, initially. If there are no vehicles triggering an inductive non-contact sensor on the main street, and if a vehicle on the side street triggers one of the inductive sensors, the light sequence should change. For the main street, the yellow traffic lights should turn on for 3 seconds, and then the red traffic lights for 10 seconds. During this period, the cars driving on the side street could go through the intersection (the green traffic lights should be on for 7 seconds and then the yellow traffic lights for 3 seconds). Then the system should reset and the sequence should repeat. This laboratory experiment was completed by students in a single two-hour lab session.

To finish the cycle, students were asked to reflect on the traffic experiment experience in the lab report. The cycle was finished with students’ homework assignment dealing with the design problems and the accompanying homework solutions presented to students as a part of class discussion.

**Cycle 4**

As a part of the activities of the first two quadrants, a number of design problems are worked out on the board. For some problems, students are encouraged to form small groups and produce
group designs. One group is selected to present their design, which is then compared to other 
groups’ designs. A design homework assignment dealing with an application of PLCs is 
assigned, corrected, and then explained in detail in the classroom. In addition, some successful 
student designs are emphasized. The laboratory assignment is discussed in the classroom. 
Students are asked to come to the lab session with tentative design solutions.

The lab design objective was to develop a PLC ladder logic for a batch process in the chemical 
industry to mix two liquids in a tank. The fluids are poured into the tank in precise amounts and 
then the mixture is emptied from the tank. According to the I/O specs given, proper wiring 
connections were to be made. Students were to implement PLC ladder logic to control the 
process. The design used the experimental setup shown in figures 2 and 3. However, the level 
indicator was hardware simulated by a motor with two relays for back and forth motion of the 
indicator. Limit switches were to present level switches. However, they behave differently than 
the real level switches. When the indicator passes by them they de-activate. Most students didn’t 
account for this in their preliminary designs. They spent two weeks in completing this lab.

During the fifth week of the PLC module, an open-book test was administered. The test 
consisted of five design problems. Students in this class performed better than students from 
the previous year when the class was offered. The test design problems were used as a learning tool 
as well as an evaluation tool. In week six, instructor discussed all the test problems. In lab, 
students completed their designs successfully and wrote a short lab report presenting only the 
obstacles they had to overcome to complete the design and reflections on what they learned.

At the end of the course, a final test including two design problems dealing with PLCs was 
administered. Almost all students’ designs were acceptable.

**Analysis and Results**

Two types of analyses/results are presented: one dealing with the learning objectives, and 
another one dealing with the student perceptions of Kolb’s cycle procedure/results. The 
implementation of Kolb’s learning cycle increased slightly the PLC test average from 67.8% to 
71.5%. Also, the students became aware of Kolb’s experiential learning cycle, through quick 
lecture and a survey based on cycle activities, as shown in Figure 6. On the left hand side of an 
activity, an average response from 12 students is reported. The students used a scale from 0 to 5, 
with 0 presenting an activity not observed and 5 an activity well emphasized in the PLC module. 
In Figure 6, grayed out activities were not observed by the students. All four quadrants are well 
represented. Field trips were not organized since this function is often performed by engineering 
student organizations (IEEE, ASME, or IIE). Usually, twice a year, students tour a 
manufacturing facility of one of the nearby companies. Journal writing as an activity was not 
reported. However, the style and requirements of lab reports are similar to a journal.
Conclusions

In this paper, Kolb’s experiential learning cycle is implemented and evaluated as a teaching method for learning PLCs in a regular computer-integrated manufacturing course offered in industrial engineering and mechatronics engineering programs. Students participated in all four-quadrant learning activities and as a result their design skills, including the use of PLCs,
improved. Furthermore, at the end of the module, students learned how to implement Kolb’s learning cycle on their own, through lecture and by filling a survey. Future developments will include an implementation and assessment of Kolb’s cycle in the remaining modules of the course. If proven successful, the entire manufacturing course sequence will be modified to complement this learning method. It is expected that the long-lasting effects of the Kolb’s cycle implementation will result in positive changes in students’, and later engineers’, approaches to learning.

Bibliography