LABORATORY BASED PROJECT FOR EXPERIENTIAL LEARNING IN PLC SYSTEMS INTEGRATION AND PLC SYSTEMS DATA ACCESS

Tom Wanyama* and Ishwar Singh**
School of Engineering Technology, McMaster University
Hamilton, Ontario
Wanyama@mcmaster.ca*
ishwar.singh@mohawkcollege.ca**

Abstract – While there many approaches to experiential learning, open-ended problem-based learning is believed in literature to be the most effective approach. However, in the teaching of engineering, this approach is resource intensive. Consequently, it is usually confined to a single capstone course in engineering programs. On the other hand, laboratory-based learning, which is one of the oldest forms of experiential learning, is less resource intensive than problem-based learning. But in its simplest form, where students are required to carry out well-structured laboratories, laboratory-based learning does not develop students' design, project management and communications skills. In this paper, we present a learning approach that combines laboratory-based learning with open-ended problem-based learning. This approach harnesses the strength of laboratory-based learning and open-ended problem-based learning approaches, while mitigating their shortfalls. In the approach, students working in groups of three to four are introduced to two areas of study, namely: Programmable Logic Controller (PLC) systems integration and PLC systems data access. Thereafter, the students are asked to develop group projects which either integrate the two areas of study, or extend the functions of the laboratories in one of the areas of study. Once the project is approved, the students are required to design, implement and test their solutions within a specified timeframe. We have received a lot of positive feedback from students about this learning approach, and in the future we would like to carry out a formal survey to determine its educational effectiveness.

Keywords: Experiential-learning, Laboratory-based-learning, Course-projects, System-integration, Process-Automation, Teaching-engineering.

1. INTRODUCTION

It is generally agreed in literature that that most people learning better by doing [1, 4]. Therefore, hands-on

learning or experiential learning is becoming one of the dominant pedagogical paradigms. While there many forms of experiential learning, open-ended problem-based learning is the most effective method of learning in the engineering field. This method allows students to practice problem solving, project management, teamwork, and systems design. This increases their confidence and enthusiasm in their education and profession [2, 5]. However, open-ended problem-based learning is very resource intensive. That is, the amount of supervision that students need in order for them to develop and implement appropriate projects that solve real life problems, and the amount of financial resources required to support those projects; are prohibitive in many ways. Therefore, most engineering programs confine open-ended problem-based learning to a single capstone project course that is usually offered in the final year of the programs. Unfortunately, by this time, students have covered many areas of the program. Therefore, they usually seek to undertake the capstone project in areas they find to be interesting, instead of taking it in the most important areas of the program, or the areas where they lack knowledge and skills. In fact, most students view the capstone project as an opportunity to showcase their knowledge and skills as opposed to an opportunity to learn.

Laboratory-based learning is one of the oldest forms of experiential learning. It generally has the following advantages over open-ended problem based learning:

- While in some cases laboratory based learning can be resource intensive in terms of capital investment, it is generally less resource intensive than open-end problem-based learning in terms of running cost. Therefore, it is possible to use laboratory based learning in many courses of engineering programs.
- It is easier to manage the learning outcomes and making it easier to harmonize the knowledge and skills learned by the students

However, laboratories have to be designed carefully in order to be an effective learning tool. Moreover, very structured laboratories generally do little to develop

student design, project management and communications skills [3].

In this paper we present a teaching and learning approach that integrates laboratory-based learning and open-ended problem-based learning. We have designed our approach in such a way as to achieve the strength of both laboratory-based learning and open-ended problem-based learning, while mitigating their shortfalls. In the approach, students working in groups of three to four are introduced to a number of laboratories for a period of nine weeks in a thirteen weeks semester. Thereafter, students are asked to develop group projects which integrate and extend various laboratories. They work on the project proposals during the tenth week of the semester. Once the projects are approved, students work on them for three weeks, and then present their work toward the end of the thirteenth week.

The rest of this paper is arranged as follows: Section 2 presents the background of our learning paradigm that integrates laboratory-based and open-ended problem-based learning. In Section 3 we describe three sample projects that students carried out in the course that was taught based on our learning model. Section 4 covers a general discussion of our learning model, while Section 5 presents the conclusion and future work.

2. BACKGROUND

The learning paradigm of laboratory based project for experiential learning was used in the course, Advanced System Components and Integration (PROCTECH 4AS3); offered by the McMaster University, School of Engineering Technology, in collaboration with Mohawk College. The laboratories of the course are classified into two categories, namely PLC system integration laboratories and PLC system data access laboratories.

2.1 PLC System Integration Laboratories

PLC System Integration Laboratories are based on an XYZ Robotic gantry table whose controller is shown in Figure 1. The table is fitted with the following components:

- Omron CS1G-CPU42 PLC
- Omron OMNUC W-Series AC Servo motors driven by R88D-WTA3HL Servo Drives (SD)
- Omron C200HW-MC402-E Motion Controller
- Omron NS-Series Human Machine Interface (HMI)
- Omron F160 vision system with Omron F60-S1 camera
- Pneumatic suction system used to pick and place objects

The gantry table can be connected to the configuration computer through an RS232 port or through Ethernet. The configuration computer has software applications used to

configure and/or program the table components, namely: CX-Programmer for the PLC, Motion Perfect 2 for the Motion Controller (MC), CX Designer for the HMI, CX Integrator for networks. The vision system is configured through a hand held console.

Fig. 1. PLC, MC and SD of the XYZ Robotic Gantry Table.

The main objective of the PLC Integration laboratories is to teach students to use software to integrate industrial sensors, actuators and controllers into systems that accomplish common tasks. We use a set of four laboratories to achieve this objective, namely:

- **Integration Lab 1 - Motion Control:** In this laboratory the Omron C200HW-MC402-E Motion Controller (MC), and Omron OMNUC W-series AC Servo motors and Servo Drives (R88D-WTA3HL) are controlled directly through a PC using Motion Perfect 2 software application by Trio Motion Technology. This laboratory has the following goals: to teach an understanding of the different commands required to move the table actuators through the terminal command window, and to write programs which are stored in the motion controller, and enable the PLC to control the actuators.
- **Integration Lab 2 - Integration of PLC and Motion Controller:** In this laboratory the Omron C200HW-MC402-E Motion Controller (MC), and Omron OMNUC W-series AC Servo Motors and Servo Drives (R88D-WTA3HL) are controlled using a PLC. The main objective of this laboratory is to familiarize students with CX-programmer software application and to integrate the motion controller and the PLC.
- **Integration Lab 3 - PLC Servo Motor Control via Programmable Terminal:** In this laboratory the Omron C200HW-MC402-E Motion Controller (MC), and Omron OMNUC W-series AC Servo Motors and Servo Drives (R88D-WTA3HL) are controlled using the Omron NS-series Programmable Terminal (PT) HMI through the PLC.
- **Integration Lab 4 - Integration of PLC, Motion Controller and Vision System:** In this laboratory the Omron F160 Vision Sensor is configured directly through the console. Thereafter, the PLC, motion controller, HMI, and the vision system are integrated to form a sorting machine. The machine

inspects a deck of cards, and sorts them based on the image stored in the vision system.

2.2 PLC Data Access Laboratories

The PLC data access laboratories are based on the principle of accessing PLC data using Open Process Control (OPC) technology. The following laboratories are carried out in this category:

- **Data Access Lab 1-** IEC61850 Power Protection laboratory: This laboratory has three main components, namely: GSI AC motor drive that acts as the three phase power source, the SEL-751A feeder protection relay, and a three phase motor that acts as the load. These three components are interconnected using CSA approved electrical cords that act as the feeders and the bus. Students first connect the SEL751 relay to a PC using a serial cable to configure its Ethernet ports and other parameters. After configuration, they access its data through the 'Modbus Poll' software application and through OPC applications using a Modbus TCP connection.
- **Data Access Lab 2 -** DeviceNET Integration: This laboratory involves configuring a DeviceNet network. Its purpose is to train students how to integrate automation components and subsystems using DeviceNet and how to access the data of the various network components using OPC technology.
- **Data Access Lab 3 -** PCI Based Profibus Communications. The purpose of this laboratory is to interface Profibus slaves with a PCI based Profibus scanner for data acquisition and process control and to develop a C++ process control program. Moreover, the data of the Profibus slaves is accessed using OPC technology.
- **Data Access Lab 4 -** OPC DataHub Applications: The purpose of this laboratory is to develop OPC based applications using DataHub software application. OPC DataHub is a powerful OPC application development tool that was developed by Cogent Real-Time Systems of Georgetown, ON. Through this laboratory, students learn the various data access technologies supported by DataHub.

2.3 Course Project

As mentioned in Section 2, the laboratories of PROCTECH4AS3 are divided into two categories, namely: PLC Integration (XYZ-Table) and Process Automation Data Access (PCs in Automation). In the course project, students are required to integrate the XYZ gantry table with the use of PCs in automation, or extend one of the two types of laboratories. Therefore, as they

carry out the laboratories, they identify the areas that they want to work on in the project. In fact, students are asked not to include a section on how to improve any of the laboratories. Instead, they are asked to identify some of the changes they would want in the laboratories, and make those changes as part of their projects. In the 9th week of the semester, students submit their project proposal which include an introduction, a background and a conceptual design. Then they work on the projects for the last three weeks of the semester

3. EXAMPLE PROJECTS

We used the pedagogical paradigm of laboratory based project for experiential learning in the Advanced Components and System Integration (PROCTECH 4AS3) course of the Bachelor of Technology program at McMaster University, in the fall semester of 2013. While a wide range of projects were carried out, we present in this paper three sample projects that we believe make a good representation of the type of projects that we carried out.

3.1 Sample Project 1: Integration of DeviceNet and IEC61850

In this project, students were able to establish communication between DeviceNet device and IEC61850 devices over the laboratory Local Area Network (LAN). To test the communication, they used a DeviceNet light stack connected to a computer through a DeviceNet PCI card to display a code representing the speed (frequency) of a motor. The power, speed, current, and voltage of the motor was monitored by a SEL751 relay based on the IEC61850 standard. Note that the SEL751 relay was connected to another computer on the laboratory LAN through a ModBus TCP port (See Figure 2).

Fig. 2. Integration of DeviceNet and ModBus TCP Devices.

As shown in Figure 2, data from the SEL751 relay was accessed by the KepServerEx V5 OPC server, making it

available to the DataHub OPC client running on the computer connected to the relay. On the lamp side, the lamp tag was accessed by the SST DeviceNet CDA OPC server, making it available to the DataHub OPC client running on the computer connected to the lamp. Data accessed by the DataHub client running on the relay computer was tunneled through the laboratory LAN and accessed by the DataHub client on the lamp computer. The lamp tag was thereafter bridged to the motor speed, taking into account the scaling factor.

3.2 Sample Project 2: Communication among XYZ-Robotic Tables over an Ethernet LAN

The XYZ robotic gantry tables used in the PROCTECH 4AS3 laboratories are fitted with a touch screen HMI. The HMI communicates with the PLC through RS-232 connection. Therefore, one cannot use a single HMI to monitor and/or control multiple tables. In this project, students connected one HMI to the laboratory LAN, and then used it to control two tables. In addition, they established communication between the PLCs of the gantry table. Figure 3 shows the physical topology of their network, while Figure 4 shows the logical topology of their FINS network.

Fig. 3. Physical Topology of the Project Network

Generally, the students wanted to demonstrate the concept of controlling multiple machines (PLCs) using a single HMI and the concept of communication among PLC controlled machines. Both these concepts are highly desirable in industry.

During the network configuration, the student realized that while the OMRON CS1G-CPU45H PLC supported both Ethernet IP and Factory Interface Network Service Ethernet (FINS Ethernet), the Omron NS10-TV01B HMI only supported FINS Ethernet. Therefore they had to configure the entire network as a FINS Ethernet network, learning a great deal throughout that process.

Fig. 4. Logical Topology of the Project Network

3.3 Sample Project 3: PC based HMI

PLC System Integration Laboratories helped the students to learn how to control motion controllers using PLC through HMIs and how to integrate the motion control system with a vision system. On the other hand, data access laboratories helped students to learn how to access process data using OPC technology. In this project, students accessed the motion control data using OPC technology (DataHub OPC server and KepServerEx V5 OPC server), and built a PC based HMI to monitor and control the motion and vision control system. Figure 5 shows that the students programmed the Motion controller through the attached PC, and configured the vision system manually. Thereafter, they integrated the pick and place system by programming the PLC. Moreover, the figure shows that the PLC program tags of interest were loaded into the KepServerEX V5 OPC server, which in turn made the data associated with those tags available to the DataHub OPC client. It is through this client that the student built an HMI to monitor and control the pick and place system based on the XYZ gantry table.

Fig. 5. PC based HMI.

4. DISCUSSION

The sample projects presented in Section 3 reveal that students who took the Advanced Components and System Integration course of the Bachelor of technology program at McMaster University in the fall of 2013, carried out a wide variety of course projects. Since those projects were based on the covered laboratories, they addressed the same set of concepts, namely: OPC data access, PLC configuration and programming, PLC system integration, integration of device connected on different industrial networks, and HMI configuration. This implies that the learning paradigm of laboratory based project provides a means for managing the breadth of the subject matter of students' projects. If this approach is used in all program courses that have laboratory components, then open-ended problem-based learning would be used in the largest part of engineering programs, a situation that is highly desirable.

Although the projects were carried out in the last three weeks of the semester, student had spent ten weeks preparing for them through their laboratory work. That is, laboratory based project learning allows laboratories to share time with projects, which is an efficient way of utilizing learning time. Moreover, the paradigm proved to have potential because the projects had 100% completion rate, with all students scoring above 80%. We also got a lot of positive feedback from the students. Finally, we would like to mention that using the laboratory based project learning paradigm allowed the students to practice problem solving, project management, teamwork, and systems design without any direct project cost to the school. Usually students practice these skills when learning through open-ended problem-based learning – a learning paradigm that is generally known to be very resource intensive.

5. CONCLUSION

In this paper we present a learning paradigm that integrates laboratory work with course projects. We believe that this paradigm harnesses the strength of laboratory-based learning and open-ended problem-based learning approaches, while mitigating their shortfalls. When we used the paradigm in the Advance Components and System Integration course of the Bachelor of Technology program at McMaster University, students were able to carry out a variety of highly sophisticated

projects that had no direct cost to the school. While the projects were carried out in only three weeks, students planned them over a period of ten weeks. This led to a completion rate of 100%, with all students scoring over 80% in the projects. Finally we would like to mention that we got a lot of good feedback from students about the learning paradigm of integrating laboratory work and class projects, and in the future we would like to carry out a formal survey to determine its educational effectiveness.

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