

## Design a Practice-Intensive Course of Programmable Logic Controller and Automation

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### Abstract

The rapid development of technology brings both the challenge and the opportunity for traditional engineering technology education. The idea of Practice-Intensive Course (PIC) is targeted to greatly improve the teaching effectiveness through hands-on and minds-on of all modules including lectures, laboratories and projects. This paper discusses and explains how to design and deliver a PIC by using the Programmable Logic Controller (PLC), one of the core Automation courses, as the case-study to achieve education innovation. This pedagogical research proposes a method by integrating knowledge, simulations, and experiments into a reversible loop to optimize the practice/experience based learning curve. Many detailed examples are provided to illustrate the proposed idea.

**Keywords:** *Programmable Logic Controller, Practice-Intensive Course, Pedagogical Research, Hands-On, Automation Technology*

### 1. Introduction

The modern manufacturing industry has been continuously revolutionized by automation technology [8]. PLC as a key process automation technology has been extensively applied in different areas ranging from food, beverage industries to steel and petroleum industries, due to its distinct advantages including flexibly, reliability, robustness, and stability [2][9][12][13]. Currently, PLC has become a commonly used technology for automation engineers, chemical engineers and manufacturing engineers [1][10][13]. PLC is based on IEC 1131-3, which is the international standard of the languages for industrial automation. It provides the guidance and rule for common elements and programming languages including data type, variables, configurations, function blocks, sequential function charts (SFC), instruction list, structured text and ladder diagram [11]. Obviously, PLC is an important course for undergraduate students, not only because the students can gain related knowledge and skills about relay ladder logic, but also because some of them will pursue the coop positions or even eventual employment in this area. Therefore, how to design and deliver a PLC course is essential. There are several obstacles need to be recognized and conquered regarding to the current PLC education. First of all, PLC is a fast changing technology. The major PLC manufactures such as Rockwell (Allen-Bradley), Siemens, Omron, ABB, Mitsubishi, GE, Schneider frequently update their hardware and software, which makes the university PLC education face increasing challenge. Secondly, PLC is a comprehensive system. It needs as least two semesters to cover most important points. Finally, PLC is practical. How to engage the students into sufficient hands-on training and

exercises must be one of the main issues to be considered in priority. In this work, the authors try to analysis and discuss how to deal with these issues in an effective way.

## 2. Proposed solutions to fix the current obstacles

### 2.1. PLC is a fast changing technology

Basically, the fundamentals and principles of most PLC devices are similar and do not change in a short period. Besides, the students should obtain the ability to transfer their PLC skills to the PLCs they have not used before.

The instructor needs to let the students be aware of the current technological development trend at the beginning of the lecture. Although there are many different kinds of PLC hardware and software, the PLC course is supposed to teach the students how to self-learn other types of PLCs which are not adopted in the course. There are some low cost PLCs in the market that the students can purchase by themselves to practice PLC programming and conduct related applications at home [3][4][5].

Assuming some students cannot figure out the differences within various PLC types, the instructor is expected to explain them when addressing the same problem with PLC. For example, the Allen Bradley PLC5000 is used in the laboratory module. While in the lecture module, the characteristics of both PLC5 and PLC5000 is explained and compared.

For instance, in RSLogix5, the input address I:1/0 is equivalent to Local:1:I.Data.0 in RSLogix5000. The output address O:2/4 is equivalent to Local:2:O.Data.4 in RSLogix5000. Besides, in RSLogix5, if one wants to create a Timer, Counter or even an integer, the related data types should be utilized. However, in RSLogix5000, it can be conveniently addressed by applying the tag names.

In this way, the students will not only figure out the differences between two PLC types, but also know how to conduct the programming based on other similar systems.

### 2.2. PLC is a comprehensive system

Different with other programming tools such as Visual Basic and C++, PLC is involved with both hardware and software. One way to make the students to learn it step by step, is to separate the PLC course into two semesters. The main content for PLC1 is the fundamentals of PLC knowledge and techniques, including the digital input, digital output, and a lot of instructions learning and applications, such as Timer, Counter, Math, Compare, Logic, Move, and Program Flow Control. For PLC2, it will be focused on the analog I/O and communications via ControlNet, DeviceNet, and Ethernet.

Furthermore, in the lab part of PLC1, some simple output devices such as relay coil, LED, seven-segment displayer are considered. In lab part of PLC2, some advanced output devices such as DC servo motor and traffic lights are applied. Because, for advanced output devices, extra hours have to be spent on explaining the principle and practice of the components/devices themselves, which is inappropriate for the basic learning of PLC at the starter stage.

### 2.3. PLC is practical

Learning by doing is proven one of the best ways for technical engineering education and training. Especially for the PLC course, how to engage the students into sufficient hands-on practices is top mission.

To put more emphasis on this, 1) a lot of case studies for practical program solving based on PLC programming in lecture module are necessary, 2) each lab should be challenging enough so that most students will not finish far before the lab ends, 3) projects are designed so that each group of two students will complete three topics including open design project.

### 3. Practice-intensive for lecture module

For lecture, basically, PowerPoint combined with programming practice on the PLC simulator is used inside and outside the classroom. PPT is to introduce the basic knowledge, and simulator is to solidify the knowledge to address the real world problems in a virtual scenario that helps the students to understand it better. Blackboard/whiteboard can be considered to explain something deeper. Handouts were given before the lecture started.

PLC is a common and popular automaton course. Traditionally, the instructors put a lot of emphasis on explaining the working principle of relay at the beginning. This developed course did not start with heavy introduction of relay. Instead of this, it focused more on the PLC programming itself. The students comprehend how relay works by conducting the related experiments. For example, as shown in Figures 1 and 2, the concepts of 'software seal' and 'hardware seal' is introduced to let the students clearly know the process how the functionality of internal contact of the relay chassis is achieved by the 'seal' circuit of the ladder logic diagram. By doing the comparative experiment of 'software seal' and 'hardware seal', both the concept of relay and the advantage of applying the ladder logic diagram to change the hardware wiring problem into a programming problem will be understood deeply by the students.

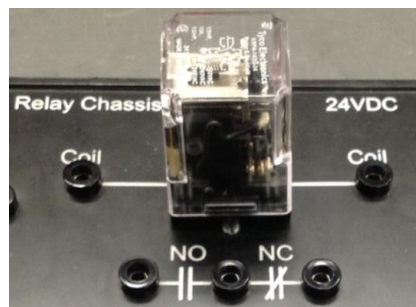


Figure 1: Relay chassis with internal contact

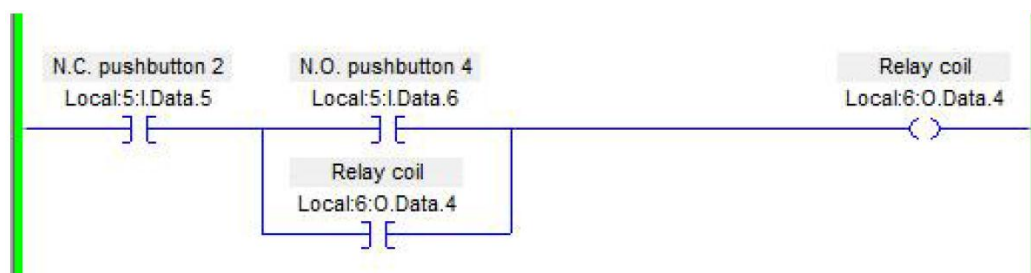
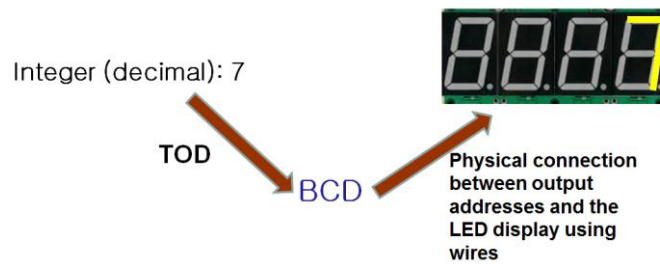


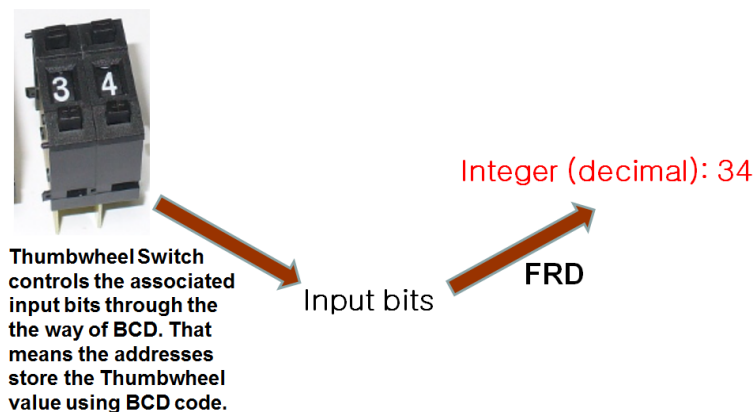
Figure 2: Sample ladder logic diagram to achieve the function of start-stop-seal of a relay coil without using internal contact

For some abstract instruction such as TOD and FRD, an effective way to introduce them is to use diagram by breaking down the process that instruction works. The major application of TOD is to show an integer on 7-segment LED display with binary-to-decimal form which is converted from decimal form, as shown in the following figure.



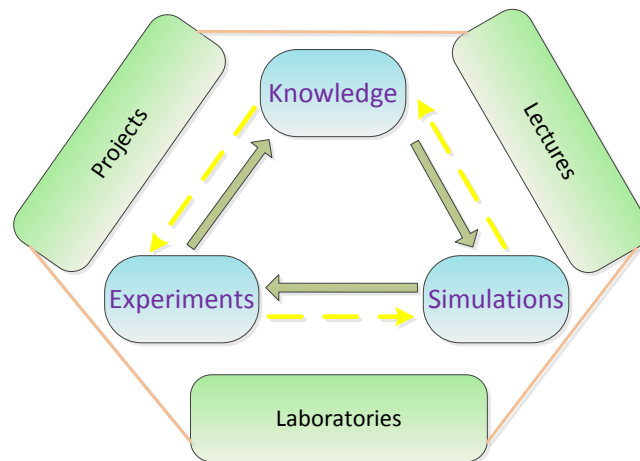
**Figure 3:** The classical application of PLC instruction TOD

Similarly, the inverted process of TOD is realized by FRD to obtain the input value from Thumbwheel Switches, store the value in the input card with BCD code and finally convert it to decimal integer.



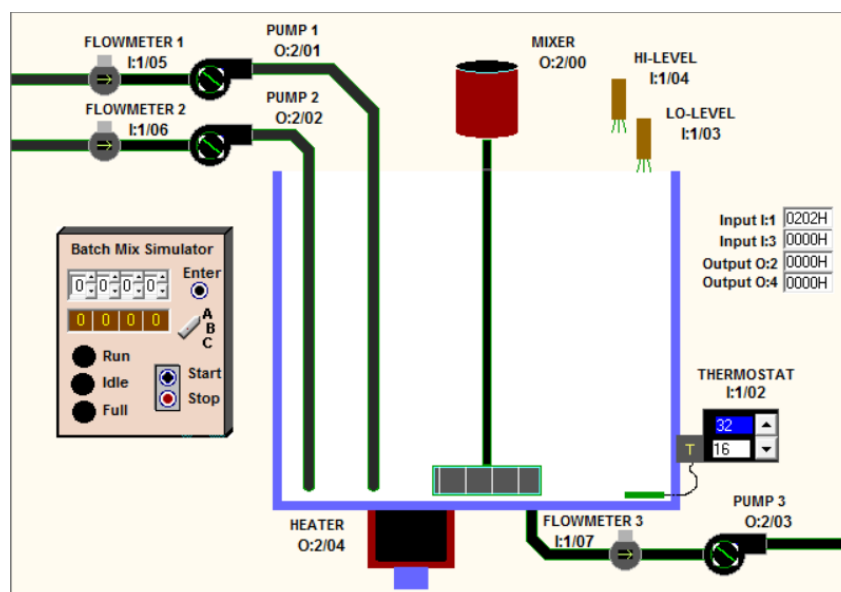
**Figure 4:** The classical application of PLC instruction FRD

To achieve the better engagement in class, a simulator called LogixPro is frequently used inside and outside the classroom. The usage of PLC simulator has following advantages. First of all, it maximizes the opportunity of the students to do the PLC programming exercise since the simulator has a similar programming environment as the real PLC. Then, the simulator self-carries various real-world simulation examples such as Batch Mixing, Bottle Line assembly, Dual Compressor, and Multi Floor Elevator Control. These simulations stimulate the students' passion and enhance their motivation of studying by applying the related knowledge to address the PLC programming issues. Finally, since the classroom has no related experimental equipment, the simulator itself works smoothly as a bridge between theoretical knowledge and practical experiments. As shown in the following figure, the simulator plays an important role in the cycle of knowledge, simulations and experiments. Generally speaking, there are two types of PLC simulators, namely software and hardware. The aforementioned LogixPro is a software simulator. In the laboratory module, hardware simulator was applied. Massive LEDs were used to mimic the on-off status of various mechatronic components/devices such as motors, valves, and sensors.



**Figure 5:** The relationship between knowledge, simulations, and experiments

Following figure illustrates the simulator of batch mixing control system. Such kind of simulator deepens the impression about how to achieve a simple process control based on sensor data acquisition/ monitoring and the parameters/status of input/output devices. It not only greatly helps the students to reach course objective but also connects this course to the entire curriculum.



**Figure 6:** Batch Mixing Tank [in courtesy of TheLeaningPit]

#### 4. Practice-intensive for laboratory module

Laboratory module is very important to help the students improve their PLC programming skills. Generally, the solutions to address one PLC programming problem are multiple. The students are encouraged to creatively think about unique approaches. Besides, the lecture module and the lab module should be highly coupled to achieve the optimal teaching effectiveness. When the knowledge point in the lecture is covered, if the students can conduct the highly associated lab in the same week, it will largely strengthen the students' ability to apply what they learned to the practical problems by both hands-on and minds-on experiments.

For instance, the Timer, as one of the most important instruction for PLC is introduced in a certain week. To solidify the students' understanding of the Timer, two related problems are designed in the lab module of the same week. One problem is about the Traffic Light Control. Two scenarios are developed as followings.

#### Scenario One: Without Left Turn Signal

Develop a ladder logic program which will turn on a set of green, yellow and red lights in the repeat sequential control of the traffic light based on Figure 7 and Table 1. (Note: in the table of sequence of operation, the address bit such as Local:6:O.Data.0 is simplified as O6:0). The students may use the lights on the external devices box to represent the traffic lights since DeviceNet has not been introduced as this stage.

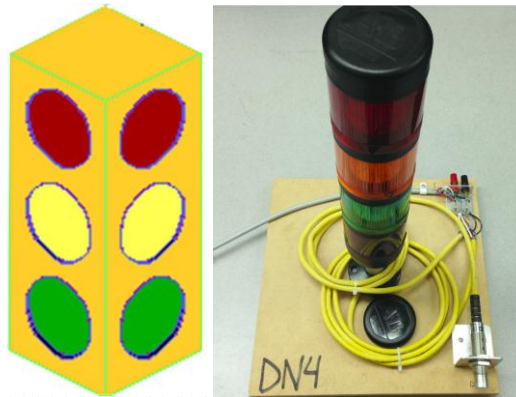


Figure 7: Traffic Light Control experiment

Table 1: Sequence of Operation

Left Red=O6:0		Left Green=O6:1	Left Yellow=O6:2	Left Red	
Right Green=O6:5	Right Yellow=O6:6	Right Red=O6:4			
12 seconds	3 seconds	1 second	12 seconds	3 seconds	1 second

#### Scenario Two: With Left Turn Signal

The students are asked to modify the existing program by add a toggle switch input. Once the toggle switch is turned on, the left turn signal will be automatically added into the sequence of operation. The left turn signal works in the following way:

Once a green light in one direction is on, a left turn signal in that direction will be illuminated for 6 seconds then off. During the 6 seconds, the first three seconds the left turn signal stays on, while the last three seconds it blinks (i.e. on for 0.25 seconds and off for 0.25 seconds, repeats for 3 seconds). Once the toggle switch is turned off, the program functions same as scenario one - without left turn signal.

The instructor can collect the common problems the students faced in the previous lab and brought it into the classroom to analysis these problems. The students are advised to do the exercises (case studies) as many as possible. Besides, the effect between the instructor and the students was mutual. If the students are interested in it, it increases the enthusiasm of the instructor as well. There are two mottoes of this course. One is "Practice, practice, and practice". The other is "Learn by curiosity, learn for innovation, and learn by thinking and doing".

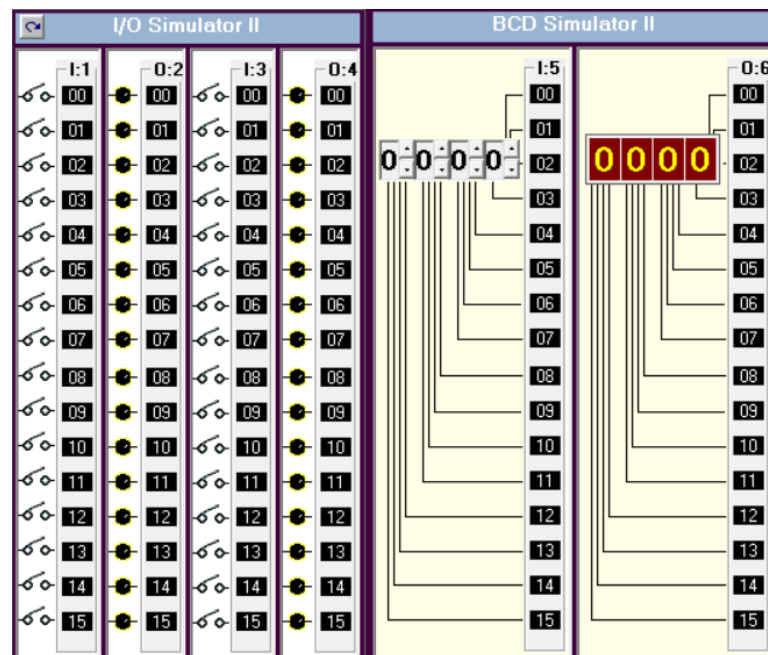
The students are also expected to address the encountered problems by individual work and team work while not by frequently seeking for assistance from the instructor.

## 5. Practice-intensive for project module

Doing project is one of the best ways to engage the students applying what they learnt to address the practical problems. Since the one of the most important purposes of engineering technology education is to train the next generation of engineers. They not only need to comprehend a lot of fundamental knowledge, but also know how to find a problem, how to design a project, how to analysis the problem, how to build the real system and test it. Finally, they also need to know how to manage a team and how to sell their product and how to be an entrepreneur.

Therefore, how to assign the students feasible, doable, interesting and meaningful projects is as essential as the project itself. In the authors' teaching practice, three projects were distributed to each group of two students.

The first project is free design project. The students were expected to open mind to define a problem and try to fix it by PLC. Use the simulator shown in the following figure to address the problem they defined.



**Figure 8:** The basic input-output simulator of LogixPro [in courtesy of TheLeaningPit]

Since most problems in the labs and tests are predesigned by the instructor, one significant drawback of this traditional and commonly seen teaching style is that the students will have less motivation to find a problem by themselves. If they are exposed in this teaching-learning style for long time, their original passion and motivation will possibly be reduced.

Thus, for this project, everything was conducted by the students themselves. Firstly of all, they were encouraged to define an engineering problem. For example, each group needs to complete the following sections.

Section 1. Find out the problems they defined.

Section 2. Write down their plans and ideas to fix the problem.

Section 3. Explain it in detail about how to solve this problem step by step using PLC.

Section 4. List all the input devices and output devices and their related addresses.

Section 5. Good documentation and sufficient analysis and discussion are required in the deliverable report.

Section 6. Is there any alternative way to solve this problem? If yes, compared with the way which is used in Section 5, which way is better and why.

As an engineer, she/he should not only address the project assigned by manager or team leader, but also can find an engineering problem, design a problem, fulfill the design process and propose the possible solutions. The engineer should also be capable to decompose and integrate the engineering system. The final year capstone project actually serves as this function to train the students engineering design abilities. However, the engineering design abilities cannot be obtained in a single course. It should span in various technical courses including PLC. This is the main purpose to design this open problem.

The students showed great interests and enthusiasms to find a real-world problem and solve it with PLC programming. For example, one student designed a Sight-Seeing Elevator. This Sight-Seeing Elevator takes resort guests from the Sight-Seeing lobby (Ground Floor) to various Sight-Seeing activities on different floors. Each floor is dedicated to a certain activity and in order to return back to the ground floor guests must take the trail down in order to get their full sight-seeing experience from the resort. Since the students conduct the project outside of the lab room. Due to the limited access to Allen Bradley PLC5000, normal elevator logic cannot be applied. However, it can be applied on the LogixPro simulator in order to tie in both lab and theory knowledge.

Another group of students applied the PLC in a home security system. Since there are many times in everyday life where it is desirable for a device to turn on and off at set times. For example, if one is arriving at home after dark it possibly will be difficult to find the doorknob and make it potentially dangerous. In this situation a light is required to automatically turn on at sunset and automatically turn back off at sunrise. The students solved this problem by creating a clock with two timers that can be set by the user. Whatever devices that are connected will be powered when the clock is between the two set points. A digital clock was generated by the cascaded combination of a 60 second timer and 2 counters, one for minutes and one for hours, where the timer would increment one counter and that counter would increment the other.

Digital Clock is another proposed project. The students are required to design a clock which should function as follows:

1. A user must be able to enter the current time in hours, minutes and seconds by using the thumbwheels and a set of toggle switches. Limits must be implemented in the program so that only valid entries are accepted (up to 23 hours 59 minutes and 59 seconds).
2. As the user enters the values, the current entries on the 7-segment LED display must be observable.
3. The clock should only start timing when an 'ON/OFF' toggle switch is activated.
4. The user is able to switch between displaying the current hours, minutes and seconds by using a set of toggle switches while the clock is running.
5. While the clock is running, the thumbwheels should not be able to change the time.



6. The time can only be changed when the 'ON/OFF' toggle switch is in the 'OFF' position.
7. Also include a toggle switch that allows the hours to be displayed in 24-hour format or in 12-hour format (AM/PM). If the toggle switch is off, it should be in 24-hour format, otherwise if the toggle switch is on, the hours should be changed to 12-hour format and a light should indicate AM (light off) or PM (light on).

Another example is to use one simulator in LogixPro to design a Silo System. As shown in the following figure, by altering the panel mounted Selector switch the operator can control the Silo System in three different operation modes. When positioning the selector switch in place A, the associated input address which is wired up to place A is triggered. Then the control system will run in continuous scenario. In this scenario, once the operator presses the start pushbutton, the entire system will run continuously and automatically unless the operator presses the stop button to halt the process. The process will resume once the start pushbutton is re-activated. Scenario B is manual restart mode. In this mode, once a loop is completed, the operator needs to manually energize the next loop by pressing the start pushbutton. The last scenario is called Fill Bypass mode. Because in real world application, the sensor is equipped to examine the condition of the container, if the container has significant flaw, it should bypass the production line without filling.

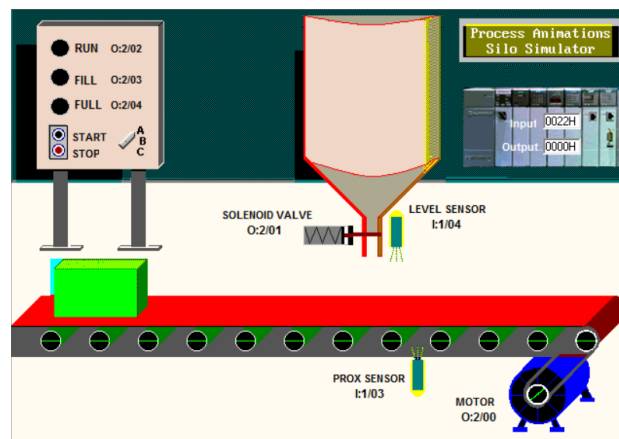


Figure 9: A Silo System based on LogixPro [in courtesy of TheLeaningPit]

## Discussions and Conclusions

In addition to the aforementioned three major components, same as many other technical courses, test is still one irreplaceable module for PLC training. As a practice-intensive course, PLC in nature put more emphasis on problem analysis and programming in both lab tests and lecture tests. For example, the following question is designed for the written lecture test. 'Assume that Rob, an engineer at Google Driverless Car Group, has three mobile robots in his garage. He designed a remote controlled system with pushbuttons on the wall besides the door. Each robot has its own start and stop pushbuttons. Any two robots may run at one time (also, any one may run by itself). However, due to the limited space, Rob cannot run the three droids at the same time. Each start button is to have a sealing circuit. Construct a PLC circuit with appropriate interlocking for this problem'. Overall, using the modules of lectures, laboratories, and projects to integrate the knowledge, simulations and experiments is the major design philosophy of a practice-intensive course of PLC and Automation. Two invaluable e-learning resources listed in the reference section [6, 7] are of equal importance to the students and instructors. Besides, most technical courses do not stand alone. At the beginning and end of this course, the instructor should relate to current/previous/forthcoming courses and consider the position of this course in the entire curriculum in terms of the students' professional training and development.

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