A Life of a Lab from Need to Retirement: A Case Study in Automation

Dr. Nebojsa I. Jaksic, Colorado State University, Pueblo

NEBOJSA I. JAKSIC earned the Dipl. Ing. degree in electrical engineering from Belgrade University (1984), the M.S. in electrical engineering (1988), the M.S. in industrial engineering (1992), and the Ph.D. in industrial engineering from the Ohio State University (2000). He is currently a Professor at Colorado State University-Pueblo teaching robotics and automation courses. Dr. Jaksic has over 80 publications and holds two patents. Dr. Jaksic's interests include robotics, automation, and nanotechnology engineering education and research. He is a licensed PE in the State of Colorado, a member of ASEE, a senior member of IEEE, and a senior member of SME.

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Abstract

This work defines ten stages of a lab lifecycle implemented in an undergraduate engineering curriculum and exemplified using programmable logic controllers in a set of lab design exercises. The ten stages of a lab lifecycle − need, conception, funding, purchasing, installation, development, deployment, enhancements, maintenance, and retirement − are compared to the lifecycle of dynamic products, which are part of the technology push market drive. Then, an example of a lab lifecycle is provided using programmable logic controllers. The intended audience for this work includes professors designing new labs, lab technicians, lab assistants, lab coordinators, and administrators. They need to understand the importance and implementation of all these stages for scheduling, personnel planning, and funding purposes.

Introduction

The importance of experiential learning, active learning, and project-based learning through laboratory experiments and exercises is well documented in educational research and practice [1-8]. Also, the lifecycle of a product is analyzed in many design textbooks [9, 10]. The engineering design process is often introduced as a part of a product lifecycle. Furthermore, some engineering curricula include sustainability modules and/or courses where a product lifecycle is analyzed through a prism of environmental responsibility such as in simplified lifecycle analysis (SLCA) [11]. In this work, the lifecycle of a laboratory experiment/exercise is defined and analyzed with respect to the concept of a product lifecycle. It is assumed that the product (in this case a lab) is dynamic, i.e. it changes with time, and that it is brought into existence due to technological advancements, the technological push. The ten stages of a lab lifecycle are need, conception, funding, purchasing, installation, development, deployment, enhancements, maintenance, and retirement. They are compared to the phases of a product development process and the product lifecycle adapted from Dieter and Schmidt [10]. Then, an example of a lab set using programmable logic controllers (PLCs) is analyzed where technological changes forced one lab setup into retirement and another into existence.

Justification for this work stems from the fact that the lab development and implementation requires a team effort, and involves a number of stakeholders, from professors, lab coordinators, and lab assistants to administrators and funding entities. Thus, a detailed description introducing the ten stages of a lab lifecycle (illustrated by a real automation lab example) can become a valuable resource for individuals in charge of lab development and deployment. While the ten stages are rather intuitive and simple, they still provide a solid base as well as a template for lab development. In addition, the comparison of the ten stages of the lab lifecycle with the introduced generic phases of a product lifecycle are intended to help faculty and administrators in justifying the timely funding for new or improved labs.

The Ten Stages of a Lab Lifecycle

Table 1 shows the ten lab lifecycle stages and their, somewhat loose, mapping with respect to a more general product lifecycle. The column on the right is based on two concepts described in Dieter and Schmidt [10], namely the product development process and the phases of a product lifecycle. While there are many similarities between the two lifecycles there are also some marked differences. Namely, the lab lifecycle deals with the lab equipment as well as the lab process (an exercise, experiment, or project). In addition, the lab lifecycle deals mostly with its education function while the product lifecycle deals mostly with its business function.

Table 1. Comparison of a Lab Lifecycle and a Product Lifecycle

Lab Lifecycle	Product Lifecycle
1. Need	1. Planning
2. Conception	2. Concept Development
3. Funding	3. Feasibility Analysis
4. Purchasing	4. Technical R&D 5. Product (Market) R&D
5. Installation	6. Testing and Refinement
6. Development	7. Preliminary Production 8. Market Testing 9. Production Ramp-up
7. Deployment	10. Commercial Production
8. Enhancements	11. Rapid Growth 12. Competitive Market
9. Maintenance	13. Maturity 14. Decline
10. Retirement	15. Abandonment

The following paragraphs describe the ten stages of a lab lifecycle in detail.

1. *Need.* Most of the labs start with a need to prove a theoretical concept using experiments or to design a process or product using modern engineering tools. Here, the later is emphasized. Often, a demonstration of a novel instrument or device is observed. Also, the current laboratory experiences are assessed and found to be inadequate or incompatible with respect to the current technology.
2. *Conception.* In this stage, mostly, replacement of the old lab's instrumentation/equipment with the state-of-the-art versions is sought; preliminary evaluations of new instrumentation/equipment capabilities are performed, and some possible new lab ideas are explored.
3. *Funding.* Funding justification is provided based on the obsolescence of the current equipment, the need to provide a pertinent experience with the state-of-the-art technology,

the need to develop new lab exercises, and in some cases for ABET and regional accreditation purposes. For more expensive devices and instruments external funding is sought.

4. *Purchasing.* The list of equipment specifications is created; vendors are contacted; a bidding process (if necessary) is conducted, and the equipment is purchased.
5. *Installation.* Here, the purchased equipment is installed. If the devices are small and relatively inexpensive the installation is performed by the lab personnel, otherwise the installation and even some training are provided by the vendor. The network access and connections are often provided by the institution's information technology personnel. The equipment is still offline, i.e., it is not used in the lab.
6. *Development*. – Replacement: In this stage, at first, only a small portion of the old instruments/equipment are replaced with the new for a pilot run. Then, the software (and possibly computer hardware) is upgraded to accommodate the new equipment while the replacement labs (the same or similar to the current labs) are developed and tested. A small group of volunteer undergraduate students (and often a couple of graduate students) are exposed to this new lab experience. The lab instructions are developed by instructors and verified by students. In parallel, some preliminary assessment instruments such as knowledge and attitude assessments are developed and tested using the volunteers.
7. *Deployment.* All the equipment is replaced; the lab instructions are complete for the replacement design problems/labs using the new equipment; all students in the lab have similar active experiences; knowledge gain and attitude surveys are implemented and results analyzed showing the successful implementation of the new equipment. Labs run smoothly.
8. *Enhancements.* Based on new, previously unavailable features of the equipment, novel laboratory experiments or design problems are conceived and implemented. However, in some cases, this stage is included in the development stage.
9. *Maintenance.* Labs, including the lab sections that implement the new features, run smoothly. The part replacements due to wear and tear are performed, and obsolescence challenges are met (new or updated software installations, operating system advancements, computer hardware changes, etc.)
10. *Retirement.* Some of the following conditions are met: equipment software updates are not supported by the manufacturer; replacement parts are hard to find and/or are expensive, new computer hardware and/or software is not supported by the equipment, or students are asking about newer versions that they have seen in industry. As a result, the now old equipment is retired.

Case: PLC Lab Lifecycle

During the last 25 years, the author has experienced a number of industrial automation equipment lifecycles (e.g. small PLCs), from General Electric's GE Series One, Allen-Bradley's SLC 100 series, MicroLogix 1000 series, to Micro800 series. The ten lifecycle stages of SLC 100 PLCs are described in detail. In this case, the transition from the GE Series One to SLC 100 series, as well as the transition from the SLC 100 to Micro800 series, is addressed. Examples of changes/upgrades in a set of laboratory design exercises are provided.

PLCs are specialized computers used in automation for controlling various industrial machines and production processes. They represent the backbone of the ongoing industrial revolution (Industry 4.0 or Industrial Internet of Things, IIoT). PLCs improved dramatically in recent years. To provide engineering and technology students with the up-to-date knowledge and hands-on experiences with the state-of-the-art technology, engineering and technology educators must adapt by creating and offering new labs. Students' engineering design experiences must be enhanced to take advantages of these enhanced PLCs.

1. *__Need.__* In 1970, PLCs were created to replace banks of relays in automation. Their main advantage is that they are programmable so that they don't need to be re-wired every time a program change is required by the process. As the information revolution progressed so did the PLCs. Figure 1 (a) is a photograph of a bank of relays while Figure 1 (b) is a photograph of one of the old GE Series One PLCs – both from author's automation lab. The GE Series One was the first "shoe box" size PLC [12]. The PLC hardware included a rack of I/Os, a power supply with a hand-held programmer, a CPU module, a cassette tape port, and peripherals such as the printer interface unit, data communication unit, and PROM writer unit. The PLC was programmed using ladder logic only.

(a) (b)

Figure 1. (a) Bank of Relays (b) GE Series One PLC

Originally, the GE Series One PLC was used to control a system of conveyor belts to illustrate how parts can move automatically from workstation to workstation in an automated factory setting. By 1990, the disadvantages of this PLC made students' use impractical. Namely, the PLC used a cassette tape for program storage, it didn't have an RS232 port for serial communication with other devices, it could not be connected to a PC running DOS, and it could be programmed only by one student at a time using the hand-held programmer. Also, at this time, any device or program that used a PC was considered a modern engineering tool. Therefore, the technological advancements pushed the GE Series One PLC into obsolescence and created a need for a new state-of-the-art PLC.

2. *__Conception.__* Even though the faculty teaching automation courses decided to keep the GE Series One PLC conveyor setup for demonstration purposes, they also decided to search for a PLC that could

a. Easily interface with a PC
b. Use an intuitive graphical user interface (GUI) for programming, execution, and monitoring of the PLC operation
c. Allow multiple students at different PCs to write and store ladder logic programs
d. Include a set of labs for learning PLC programming

An Allen-Bradley (AB) SLC 150 PLC with a PLC trainer and PCIS programming environment running in DOS on a PC was able to satisfy all the above requirements. Figure 2 depicts an AB SLC 150 PLC.

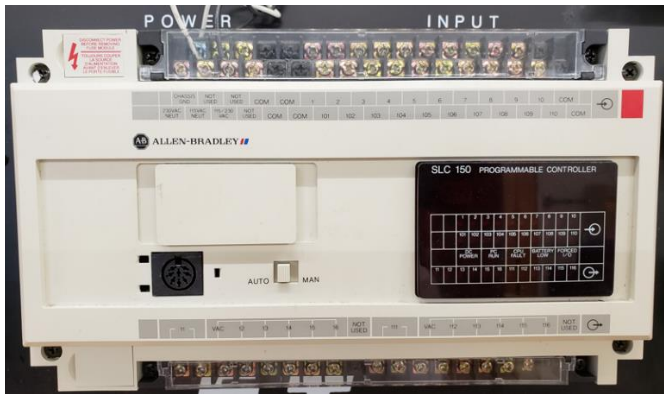

Figure 2. Allen-Bradley SLC 150 PLC

3. *Funding.* Here, the major justification to the department head for funding was compliance with ABET Criterion 3, Student Outcome k. "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."
4. *Purchasing.* Colorado State University - Pueblo is a state institution which has strict purchasing procedures based on the amount of the purchase. In this case, we decided to purchase two PLCs, one SLC 150 and one SLC 100 (SLC 100 has fewer I/Os than SLC 150) as well as one PLC PC-1600 trainer. Also, we purchased few PCIS programming environment licenses. Since the purchase amount was under $5,000, the purchase was authorized by using a purchase order only. Otherwise, the equipment specifications would have to be created and a list of vendors (at least three) would have to be supplied to the Purchasing Departments. They, in turn, would have to invite the vendors for bids.
5. *Installation.* The faculty who were teaching automation courses installed the SLC 150 PLC, connected the appropriate inputs and outputs for a sample lab exercise, installed the software, and connected a PC to the PLC according to the PLC manual [13].
6. *Development.* Since the GE Series One PLC was left to control the system of conveyor belts, two new lab exercises were developed. The first lab exercise was created to help students learn to navigate the PCIS environment, create a program from step-by-step instructions, upload the program to the PLC, execute the program, and monitor the program execution on the PC. The entered PLC ladder logic diagram presented a solution to the following design problem:

   A polishing operation requires a 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 are installed. An Allen-Bradley SLC 150 PLC is used as a controller. When the motor is running forward the tool is moving to the right. When the motor is running in reverse the tool is moving to the left. Design and implement ladder logic control for this system for the given I/O configuration.

An additional more encompassing design problem dealing with the mixing of two liquids in a tank was also prepared.

Write and execute a ladder logic control program for an Allen-Bradley SLC 150 PLC that will perform the following:

1. *If the tank is not empty, empty it by using a pump and its manual pump switch.*
2. *Open the valve regulating the flow of the first liquid to allow the first liquid to flow into the tank until its level sensor is reached.*
3. *Close the valve regulating the flow of the first liquid.*
4. *Open the valve regulating the flow of the second liquid to allow the second liquid to flow into the tank until its level sensor is reached.*
5. *Close the valve regulating the flow of the second liquid.*
6. *Pump the mixture out of the tank until the EMPTY sensor detects no presence of the mixture.*
7. *Repeat the process (steps 2 to 7) until the ON switch is deactivated.*

The two design problems were first tested by three undergraduate student volunteers and one graduate student. The above problem statements were derived based on student comments where some points were clarified and errors corrected. The PLC software is installed on all the PCs in the automation lab.

7. *Deployment.* All the students in the lab were able to access and use the PCs to create and save their PLC ladder logic programs. A special procedure is established for access to the PC connected to the PLC. At first, students used floppy disks to store and then transfer their programs to the PC connected to the PLC. Labs run smoothly.
8. *Enhancements.* Using serial port switch boxes, more computers are connected to the PLC wired to the PLC trainer. There is still an established procedure when connecting to the PLC. A new lab exercise is developed based on a model of a road intersection with miniature LED-based traffic lights and sensors detecting the presence of toy cars waiting at the intersection. The labs provide a powerful set of exercises for learning PLC ladder logic programming and automation. Students' surveys show great appreciation for the labs developed.
9. *Maintenance.* This lab set was offered for over 20 years. The equipment obsolescence challenges were met successfully. The major threats to the lab were the operating system (OS) upgrades and changes. As DOS was replaced by Windows OS, the DOS programs were less and less compatible with Windows. Also, the PC hardware changes had to be addressed in a timely manner. Placing the lab PCs on the network allowed students to simply access their files from any PC in the lab including the one connected to the PLC. Others used their USB drives for file transfer since the newer PCs did not have floppy

drives. Later, since most of the new PCs are delivered without a serial port, a serial-to-USB converter was used to keep the PLCs operational.

10. *Retirement and start of a new lab lifecycle.* Rockwell Automation, the company that produced AB SLC 100 PLCs stopped supporting the DOS-based PCIS programming environment and its SLC series PLCs. There were no new updates of the software for Windows. Most of the students coming back from their internships were commenting on the features of the new PLCs. Technological advancements creating new features like direct network connections (or USB connections) of PLCs to PCs, new human machine interface (HMI) devices with touch screens, connectivity to cell phones, multitude of programming languages and methods to program PLCs, and advanced functions like PID tuner function drove AB SLC 100 PLCs into retirement due to obsolescence. In order to retire a product some other product must take its place. We have selected, purchased, and installed Rockwell Automation's Allen-Bradley Micro820 PLCs with PanelView 800 HMI terminals as shown in Figure 3. Micro820 PLCs use Windows-based Connected Components Workbench (CCW) integrated development environment (IDE) for programming and configuring Micro800 PLCs [14]. While the advances in hardware are impressive, the advances in PLC software are even more prominent.

(a)

(b)

Figure 3. (a) AB Micro820 PLC (b) HMI PanelView800 Terminal

Conclusions and Future Work

This work defines and analyzes lifecycles of labs. It is meant as a guide to the various stakeholders (professors, lab coordinators, lab technicians, administrators, and funding personnel) involved in lab development and implementation. The ten stages of a lab lifecycle are identified and explained. A lab lifecycle is compared to that of some other products (fast-changing and technology-dependent) to create logical connections with general product lifecycle concepts. An example using programmable logic controllers in automation labs is analyzed in detail. It is hoped that faculty who wish to develop new labs will consider the ten stages of the lab lifecycle as a guide and justification when creating new labs. In addition, given the described framework, the stakeholders can evaluate their existing labs with respect to labs' lifecycle for future planning. This work could be further extended to include the time analysis of all the activities related to a lab lifecycle. An example could include evaluation of all labs for a single course or even an entire lab environment for an educational technology-intensive program.

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