2006-545: COGNITIVE SUPPORT FOR LEARNING PLC PROGRAMMING: COMPUTER-BASED CASE STUDIES

Sheng-Jen Hsieh, Texas A&M University

Sheng-Jen ("Tony") Hsieh is an Associate Professor and member of the Graduate Faculty at Texas A&M University, College Station, TX. He holds a joint appointment with the Department of Engineering Technology and the Department of Mechanical Engineering and is a Halliburton Faculty Fellow for 2005-2006. His research interests include intelligent manufacturing system design, virtual instrumentation, thermal profiling for process and product characterization, and simulation and modeling. He is also the Director of the Rockwell Automation Laboratory, a state-of-the-art facility for education and research in the areas of automation, control, and production systems. Dr. Hsieh received his Ph.D. in Industrial Engineering from Texas Tech University, Lubbock, TX.

Landon Gray, Texas A&M University

Landon Gray is a graduate student in the College of Architecture at Texas A&M University.

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Cognitive Support for Learning PLC Programming: Computer-Based Case Studies

Abstract

Students who wish to learn programmable logic controller (PLC) programming often face many obstacles. For example, many lack experience using automated systems and have difficulty visualizing programming situations. In addition, information needed for programming, such as input and output connections, is often not readily apparent. Finally, students may encounter cognitive overload because they need to be able to recall many different types of information at once, such as system component characteristics, system operation, PLC command syntax, and control program development. Instructors must use methodologies such as scaffolding and fading to provide cognitive support to students until programming tasks become more second nature.

To help students learn to write PLC programs to control automated manufacturing systems, a series of computer-based case studies are being developed. These case studies include animations of automated systems to help students to visualize how processes work and the sequence of events. They also illustrate steps in the programming process from identifying the sequence of events and input and outputs to developing code to implement each event. Although the idea of case studies itself is not new, the combination of case study methodologies and instructional technology to teach PLC programming is relatively novel. This paper will describe the case studies that have been developed so far, how they are being used, results from student evaluations of these case studies, and future directions.

1. Introduction

The programmable logic controller (PLC) has been described as one of the most ingenious devices ever invented to advance the field of manufacturing automation[1]. Thousands of PLCs have been used for such applications as monitoring security, managing energy consumption, and controlling machines and automatic production lines. As an essential part of manufacturing automation, PLCs are covered in many automation and control-related courses, such as Computer-Aided Manufacturing, Computer-Integrated Manufacturing, Industrial Control, and Manufacturing Automation and Robotics. Students from other disciplines are also exposed to PLC technology. Research by Frost & Sullivan indicates that the world market for programmable logic controller will continue to grow as units become smaller, more functional, and more able to work in tough environments[2]. The total PLC and software market was projected to reach $8.6 billion in 2000. This trend is likely to continue to increase as the world economy grows. There is a great need for engineers with strong skills and knowledge in this area.

A goal of engineering education is to prepare students for industry by exposing them to the types of tools and equipment they will need to use on the job. Lab experiences are an integral part of the student learning process, especially within science and engineering[3,4]. Edward[5] has described the purposes of lab exercises as follows:

- Cognitive learning, which is often elucidated as the integration of theory with practice.

- Inquiry methodology, which includes hypothesis forming, experimental design and methodology and evaluation of results.
- Vocational aims, which include awareness of current practice and the inculcation of professional ethics.
- Development of personal skills, such as communications, report writing and teamwork skills.

Unfortunately, educational institutions often lack the resources needed to help students to become proficient with equipment. For example, a Manufacturing Automation and Robotics course typically uses programmable logic controllers, sensors, robots, and machine vision systems in teaching automated manufacturing system design. However, students' learning is hindered by obstacles such as:

- High faculty-to-student ratios: For example, the ratio for Manufacturing Automation and Robotics at one major university is 1:36 for lectures and 1: 18 for each of two lab sections.
- Limited lab access: Students may only use equipment during scheduled lab times.
- Limited resources to support students outside labs and the classroom: In many cases, no lab assistant support is available.
- Limited equipment to support lab assignments: Because lab equipment is often expensive, students must often work in groups. For example, an industrial scale PLC—such as an Allen Bradley RSLogix 5550 processor and a set of I/O cards—costs about $8000.

To help offset these obstacles, in recent years, a variety of computer and networking technologies have been developed. For example, remote laboratories (also known as e-Lab, Tele-Lab)[5,6], virtual laboratories[8,9,10,11], and hybrid laboratories[6] have been developed to reduce lab equipment setup costs and increase accessibility. Other developments include the use of interactive[9], multimedia-enhanced[12,13], and integrated[14] approaches and the Design-Build-Test concept[15] to make learning more interactive and visual. However, there have been relatively few attempts to use technology to teach PLC programming.

The author was recently awarded a National Science Foundation grant to develop an Integrated Virtual Learning System (IVLS) for PLC education that incorporates intelligent tutoring systems, simulations, and animations. A prototype version of this system, known as *Virtual PLC*, can be found at <http://etidweb.tamu.edu/hsieh/Hsieh_VirtualPLC.html>. Previously reported work includes the design, development, and successful evaluation of *Virtual PLC* courseware on the topic of PLC timer instructions[16,17] and a ladder logic toolkit[18]. This courseware was found to be instructionally effective, and students' subjective impressions of the system were positive overall. However, the focus of these lessons was on the *usage* and *syntax* of PLC instructions.

This article describes the design and evaluation of case studies for the *Virtual PLC*. These case studies are intended to help students to visualize how an automated system should work and to understand how to control a real-life or close to real-life system using ladder logic. They also allow students to manipulate an animated model of the system in order to explore what happens under different conditions.

2. Case Study Design Overview

Case studies were developed using Macromedia Flash. This tool allows rapid development of graphics and animations, and includes a programming language called ActionScript, which facilitates development of interactive programs and interfaces. Flash files are also quite small and can be embedded in HTML pages and accessed via the Web.

There are two different designs for these case studies: *extended case studies*, which include a detailed description of the reasoning process underlying the development of a PLC program for an application; and *illustrative case studies*, which simply illustrate an application to be developed.

All the case studies begin with a problem statement and utilize a standard design (Figure 1). Each page contains a banner, progress bar, navigation/home buttons, as well as the case study content. The banner displays the title of the case study and institutional info. The progress bar, located in the top-left corner beneath the banner indicates which part of the case study the learner is currently viewing. The navigation buttons in the bottom right and left corners of the page allow learners to move to the previous, next, or first screen of the case study.

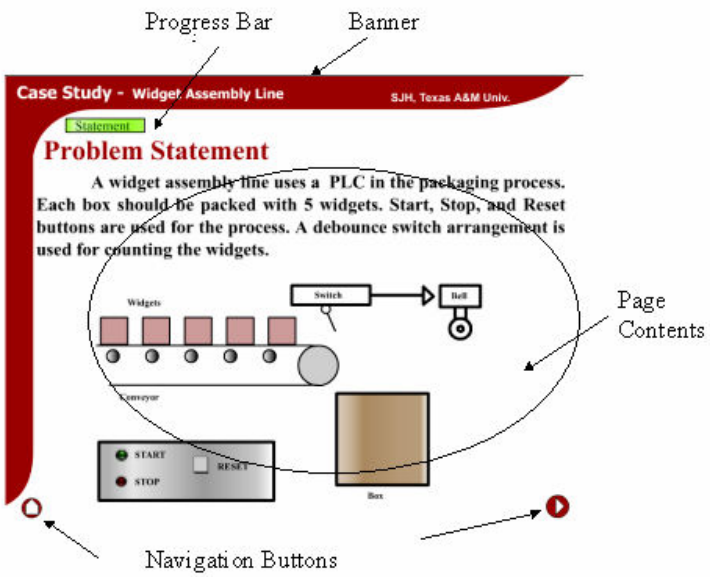

Figure 1. Problem Statement Page with Standard Design Elements Indicated.

3. Extended Case Studies

Extended case studies were developed for widget assembly, jean washing and injection molding operations. Problem statement pages for these operations are shown in Figures 1 and 2. In addition to a problem statement, extended case studies also include sequence of operations (setup), an animation of the physical system, and a case analysis. The case analysis includes input/output port assignments and translation of operations into ladder logic.

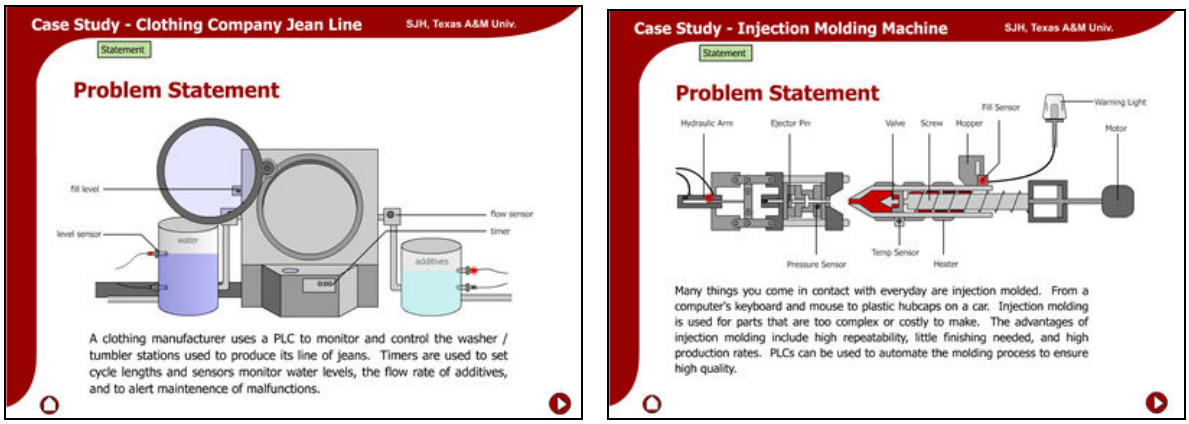

Figure 2. Problem Statement Pages for Extended Case Studies on Jean Washing and Injection Molding Operations.

Setup. The Setup screen contains a graphic illustrating the overall system layout—including the work piece, sensors, control panels and other system components—and the sequence of operations (Figure 3). This page helps users to visualize the overall system components and functionality.

Animation. After students have been introduced to the system setup and sequence of operations, an animation is used to illustrate how the automated system should work (Figure 4). Features of the animation include:

a) 3D animation
b) Realistic buttons
c) Smooth animation movements
d) Gradient colors for a more realistic look

Students use Start and Stop buttons on a virtual control panel to view the animation. These controls allow them to better understand the functionality of the system.

Case Analysis. The heart of the case study is the case analysis, which breaks a problem down into smaller steps, such as determination of input and output devices, input and output port assignments, sequence of events, and problem solutions.

a) Determination of Inputs and Outputs

The first step in developing a PLC program is to determine the input and output devices. Examples of input devices include switches, pushbuttons and sensors. Examples of output devices include motors, conveyors, and alarms. In the case studies, the inputs and output devices are identified graphically by highlighting appropriate areas of the animation. Figure 5 shows an example of highlighted input and output devices.

b) Determination of Input and Output Ports

The second step in developing a PLC program is to assign I/O ports for each of the input and output devices identified in the first step. Here again the case study employs a short animation to show how ports are assigned for each input and output device. Different colors are used to differentiate between inputs, outputs, and terminal addresses. In addition, each input/output is assigned a tag name (such as Start_1 and Bell).

c). Problem Solution

The Problem Solution section demonstrates how to construct ladder logic using the information derived in the previous steps. The original sequence of events is revised by replacing the original input/output names with the newly assigned tag names. Then the *if-then…else* statements are converted into ladder logic rung by rung. The reasons for each rung condition are each explained on a separate screen. The ladder diagram is drawn in blue with the tag names in black, which conforms to ladder diagramming conventions used in Allen Bradley RSLogix 5000 PLC software.

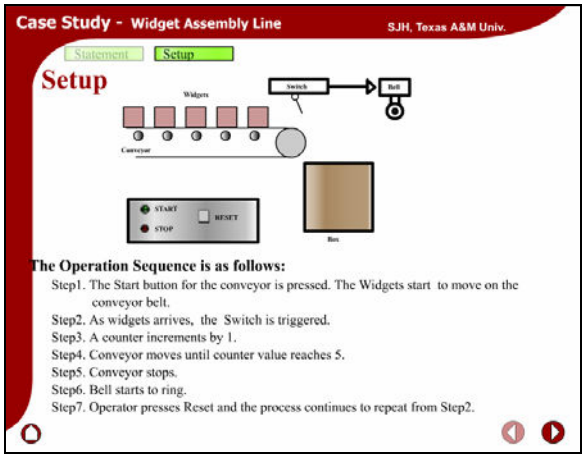

Figure 3. Example of Setup page.

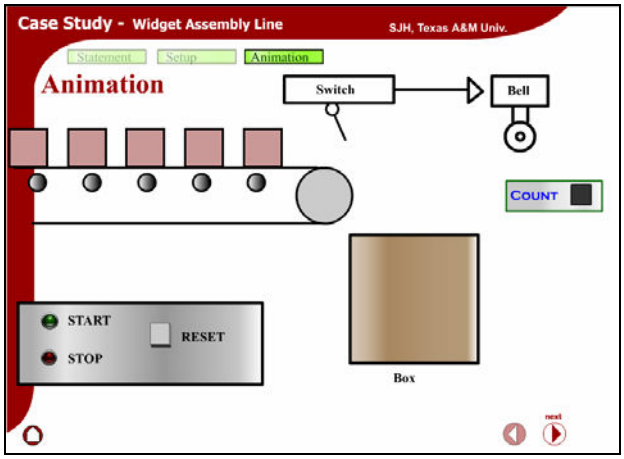

Figure 4. Example of Animation page.

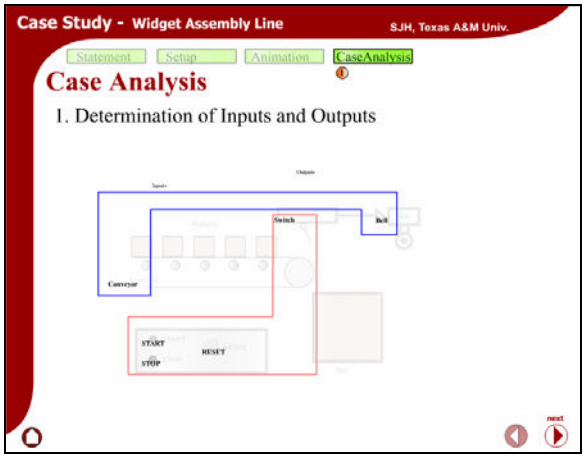

Figure 5. Highlighted Input and Output Devices.

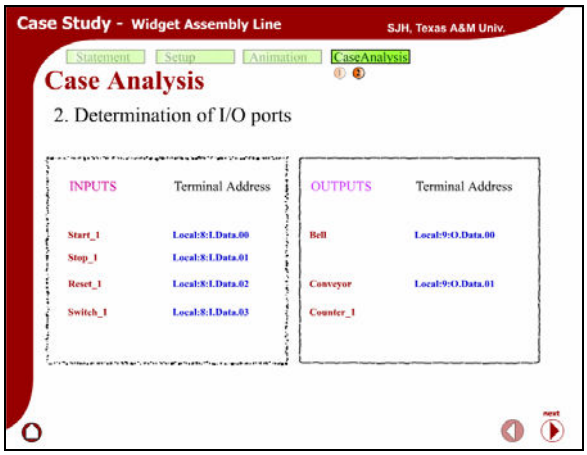

Figure 6. Assignment of Input/Output Devices to Tag Names and Addresses.

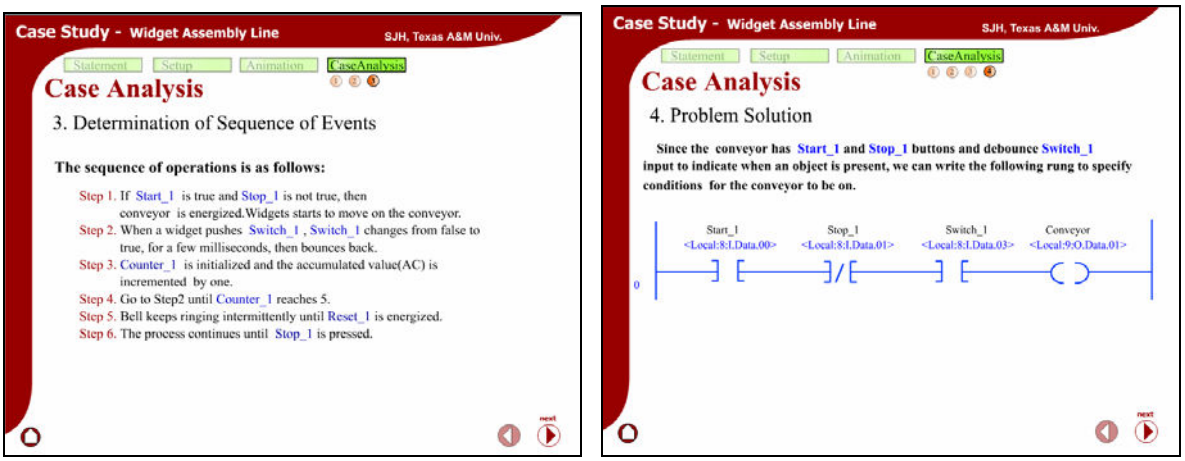

Figure 7. Revised Sequence of Events and Problem Solving Pages.

4. Illustrative case studies

Illustrative case studies include only a problem statement and an animation of the physical system. They are designed to be used to supplement lab exercises and homework assignments by helping students to visualize system structure and functions. Figure 9 shows examples of illustrative case studies for Wind Turbine Shutdown and Molten Metal Recycling operations.

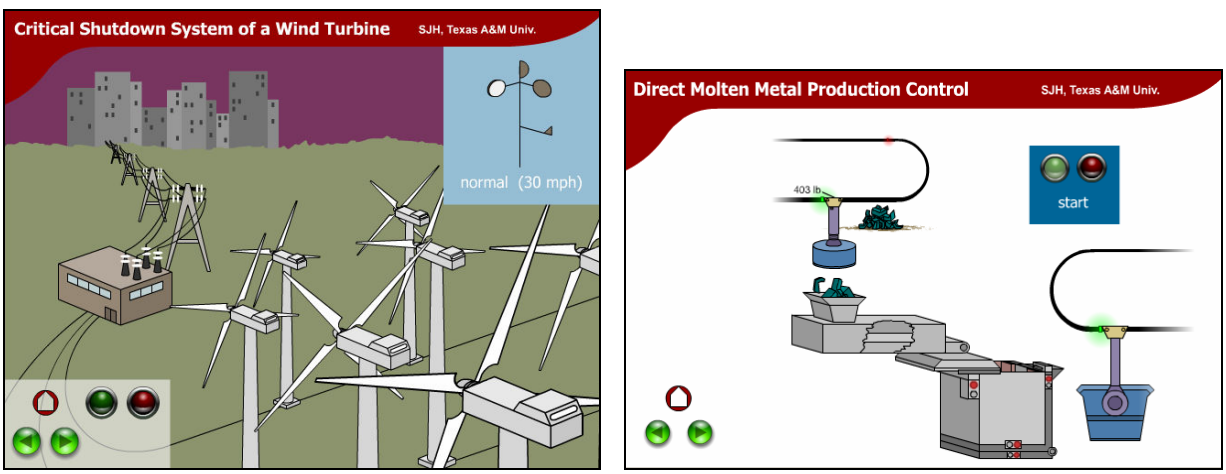

Figure 9. Illustrative Case Studies for Wind Turbine Shutdown and Molten Metal Recycling Operations

5. Methodology

A preliminary evaluation of the case studies was conducted with undergraduate students to find out:

- Do the case studies help students to learn more about PLC programming?
- Student opinions about various aspects of the case studies, such as effectiveness, ease-of-use, and relevance to their education
- Student comments

5.1 Participants, Materials, and Experimental Procedures

Participants. Participants in this evaluation were 24 undergraduate students who were learning how to program ladder logic. Evaluation activities took place during lab time. There were two labs of 12 students each.

Materials. The evaluation instrument consisted of a five-item opinion survey with a space for comments. The survey asked students to rate various characteristics of the case studies on a 7-point Likert scale. Figure 10 lists the survey questions.

Procedure. Because the instructional effectiveness of the case studies was unknown and because we did not want the evaluation activities to interfere with students' learning, the unit on PLCs was taught in the usual way with lectures followed by lab. The evaluation activities were treated as additional lab activities and took place near the end of the semester.

1. The case studies helped me learn more about PLC programming.
Strongly disagree 1 2 3 4 5 6 7 *Strongly agree*

2. I would like to have more case studies like these available to help me learn.
Strongly disagree 1 2 3 4 5 6 7 *Strongly agree*

3. These case studies were relevant to my education.
Strongly disagree 1 2 3 4 5 6 7 *Strongly agree*

4. The content of the case studies was easy to understand.
Strongly disagree 1 2 3 4 5 6 7 *Strongly agree*

5. The animations helped me visualize the process.
Strongly disagree 1 2 3 4 5 6 7 *Strongly agree*

Figure 10. Opinion Survey Questions.

6. Data Analysis and Results

This section summarizes the data gathered using the methodology described in the previous section. Results are presented in terms of student attitudes (as measured by the opinion survey), and student comments.

Opinion Survey. Figures 11 and 12 summarize the means for the opinion survey questions. Student ratings were positive for all items. In general, students felt that the prototype was interactive, relevant, and easy to use and understand.

Student Comments. Regarding the extended case studies, several students commented that they liked seeing the animation followed by the program. They also appreciated seeing realistic and relatively complex programming problems. The most commonly mentioned suggestion for improvement was the addition of more case studies. One student suggested that it would be

helpful have the ladder diagram alongside the animation so that learners can see the program in action.

Regarding the illustrative case studies, students felt that these types of case studies felt them to better visualize the programming problem. Suggestions for improvement included 1) the addition of more case studies; and 2) the inclusion of PLC code for implementing the illustrated systems.

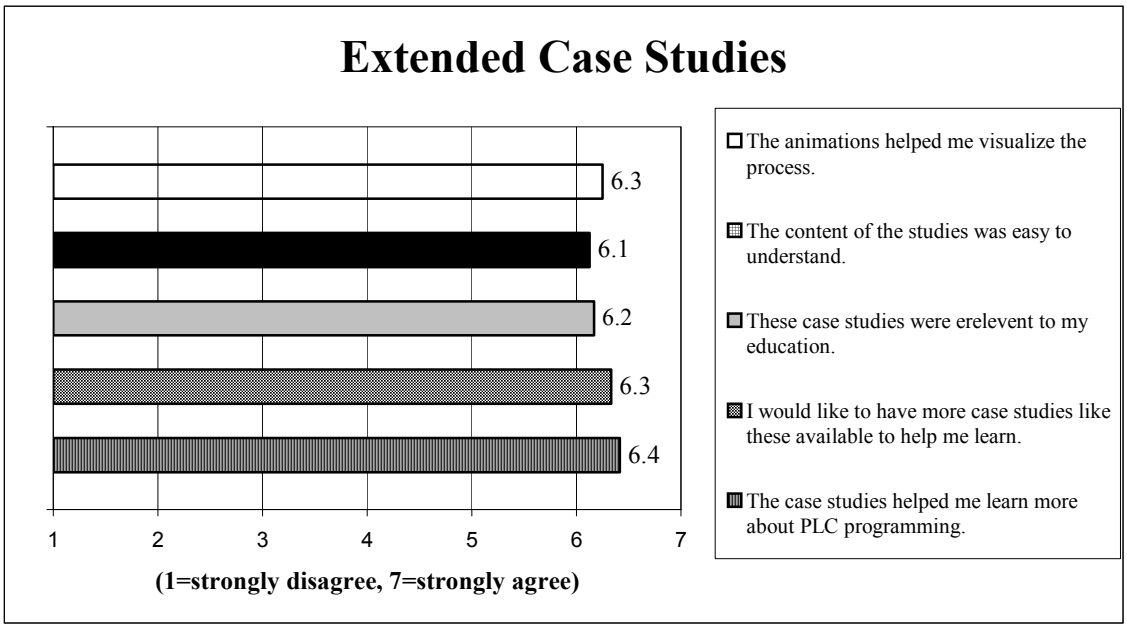

Figure 11. Opinion Survey Means for Extended Case Studies.

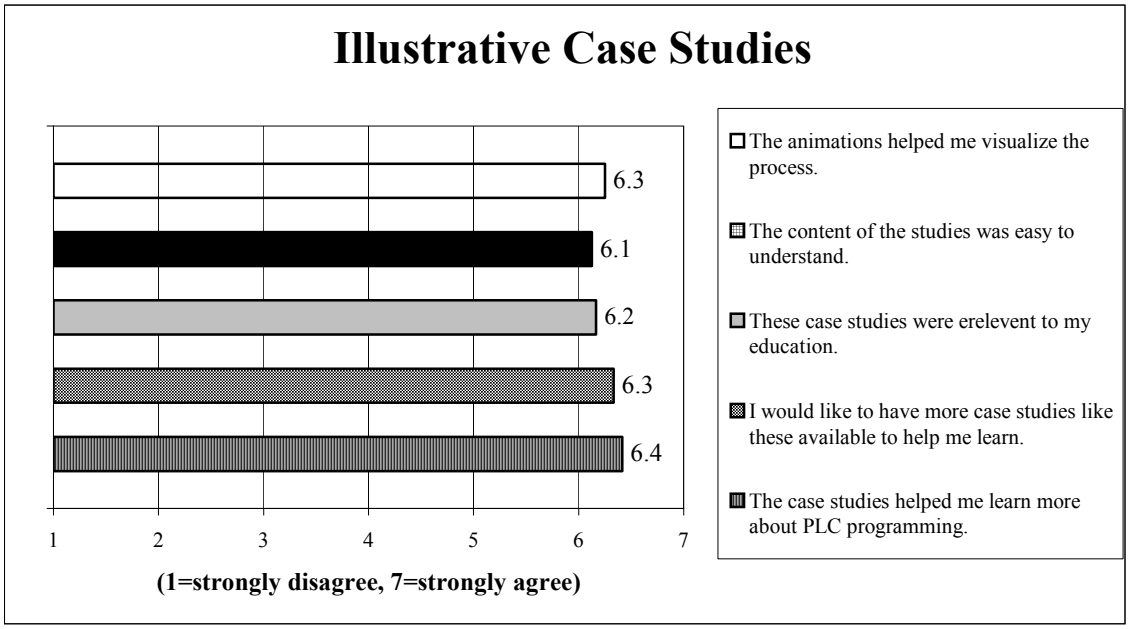

Figure 12. Opinion Survey Means for Illustrative Case Studies.

7. Discussion

These results suggest that designs for the extended and illustrative case studies are instructionally effective, and that students' subjective impressions of the system are positive. It appears that we may safely continue to develop similar types of lessons. In the future, parallel pre- and post-tests will be given to allow us to better assess how much students learn from the case studies.

8. Conclusion and Future Directions

This paper has described continuing steps in the process of developing an Integrated Virtual Learning System, called *Virtual PLC*, for programmable logic controller education. So far, evaluation results have been very encouraging. Possible enhancements include the placement of ladder logic for case study applications alongside the animations for the applications and adding solution code to the illustrative case studies.

More *Virtual PLC* lessons are currently under development. Future lessons will incorporate games and teaching program debugging. Also, the programming language will be extended from ladder logic to functional block diagrams. The ultimate goal is to create a complete system that can be used not only by undergraduate students, but also by high school students and industry professionals.

Acknowledgments

This material was supported by a National Science Foundation Course, Curriculum, and Laboratory Improvement (CCLI) grant (No. 0341287) and a gift from Rockwell Automation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation or Rockwell Automation. Landon Gray and Arun Kumar's programming efforts were instrumental in making this vision become reality.

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