The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #41899

Interactive and Web-based Animation Modules and Case Studies for Automated System Design

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Interactive and Web-based Animation Modules and Case Studies for Automated System Design

Designing, building, and maintaining an automated system is a complex task requiring knowledge of hardware and software, and how to interface components such as sensory devices and controllers. Students often lack a system level perspective of automated systems and how each component contributes to a system. Mastery of these concepts and skills is made even more challenging by limited availability of equipment, limited lab time, and lack of system-level lesson plans. To alleviate these challenges and to make learning system integration concepts accessible, efficient, and interesting, interactive modules on sensors, programmable logic controller (PLC), and robot controller interfacing and case studies are being designed and evaluated. A group of 49 undergraduate students enrolled in a manufacturing automation and robotics course learners reviewed one of the developed case studies and provided feedback about its design and usefulness. Results suggest that the case study's animation and case analysis components helped them to understand the steps involved in automating a process. A strong majority of participants agreed that they would like more case studies like this one (85.7%) and that the case study was relevant to their education (83.7%). Suggested improvements include clearer instructions and explanations and a zoom function to make the details in the schematic easier to see.

1. Motivation

Automated system integration involves the design, interface, and troubleshooting of an automated system—such as a robotic welding system, which integrates a robot, conveyor, fixture, sensors, and actuators for loading and unloading parts. As noted in earlier work [1], the ability to integrate components and devices to form an automated system is a complex and multi-faceted cognitive skill, requiring multiple layers of knowledge, including:

1. Functions and specifications of hardware devices—such as sensors and motors—and the input/output (I/O) port connections on a programmable logic controller (PLC);
2. How to interface external devices and equipment to the PLC.
3. How to write a PLC program to integrate and orchestrate the activities of the input and output devices; and
4. How to troubleshoot system problems due to interface and/or programming issues.

To address this gap, the author's team has been building an integrated, adaptive, and web-based problem-solving environment (I-PSE) known as Automated System Integration Tutor (ASI Tutor). ASI Tutor will include interactive web-based instructional modules to help students learn PLC interfacing concepts such as ladder logic and I/O devices, basic wiring, and interfacing with bridge devices; intelligent tutoring system; and virtual/remote labs. These modules will be inter-connected and designed to support one another with a goal of increasing user interaction and engagement. The focus of this paper is on the design, development, and preliminary evaluation of the case study components of ASI Tutor.

A study by Hsi and Agogino [2] suggests that the use of case studies for learning engineering design has a positive impact on generating excitement about engineering, conveying industry "best" practices, and demonstrating the design process. Hsieh [3] has noted that automated system integrators often recall other systems they have seen or worked on previously in coming up with conceptual designs. ASI Tutor will include case studies on machine and system design; and on discrete, continuous, and hybrid manufacturing processes.

2. Case Study Design

ASI Tutor case studies are designed to walk learners through the steps needed to automate a process. A case study consists of:

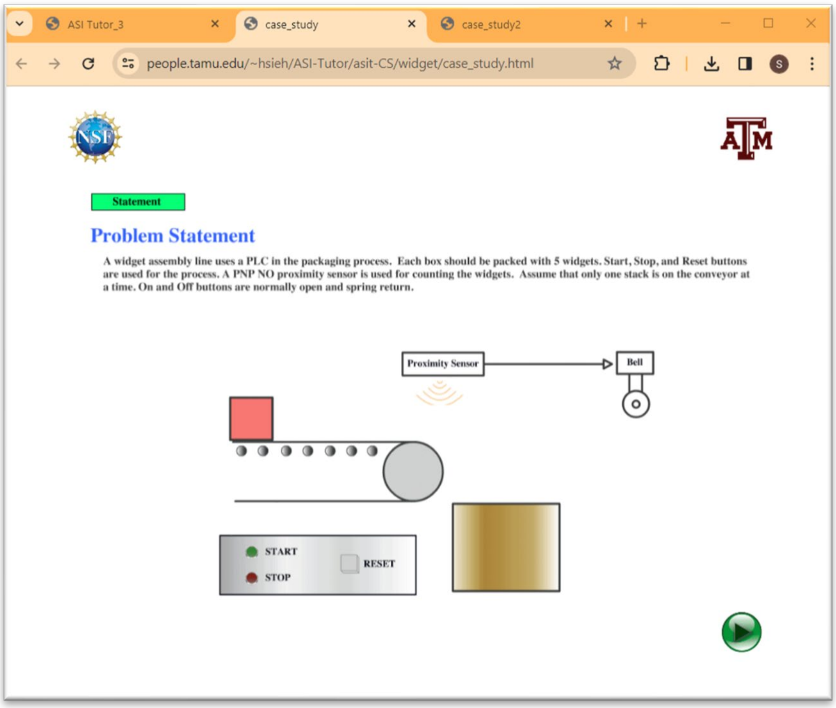
- a problem statement that provides an overview of the process to be automated
- the setup, which describes the desired sequence of operations
- an animation that shows the automated process in action.
- a case analysis that walks the learner through identifying inputs and outputs, determining I/O ports, determining the sequence of events, and developing ladder logic to control the process.
- a schematic that identifies the power rating requirements and I/O port assignments for all devices used in the process and the wiring sequence
- an opportunity to practice interfacing

These steps follow the same cognitive process used by system integrators in building an automated system. Research on situated cognition suggests that realistic practice in authentic learning environments leads to better transfer of skills [4, 5].

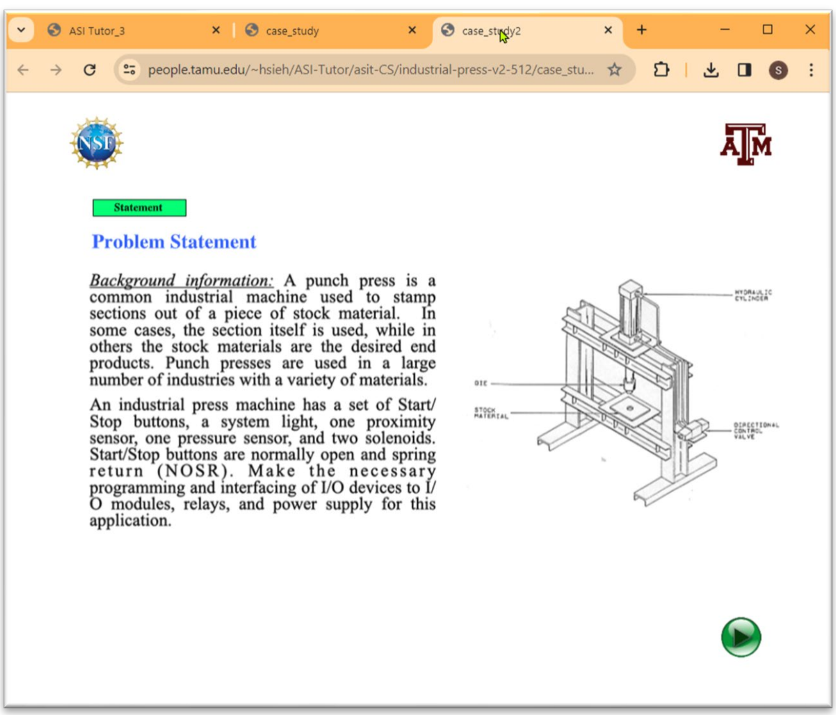
3. Development

So far, two case studies have been developed: a generic one on a widget assembly system and a more realistic one focusing on an industrial press process. Case studies were developed using Adobe Animate.

Figure 1 shows the Problem Statement screens for both systems. The problem statement describes how the system should work and provides an illustration of the system with relevant parts labeled.



(a)



(b)

Figure 1. Case study problem statement for (a) Widget Assembly Line; and (b) Industrial Press

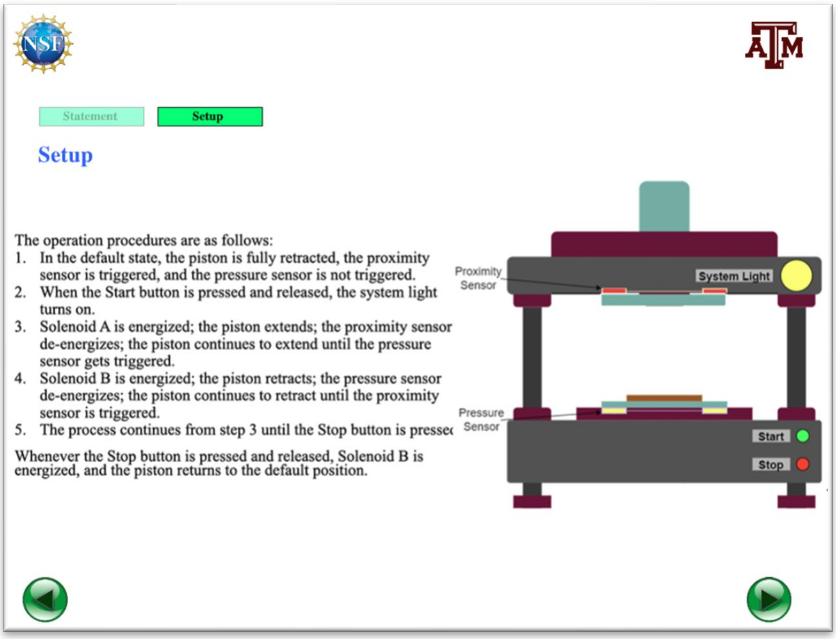


Figure 2. Setup Screen showing sequence of operations for industrial press

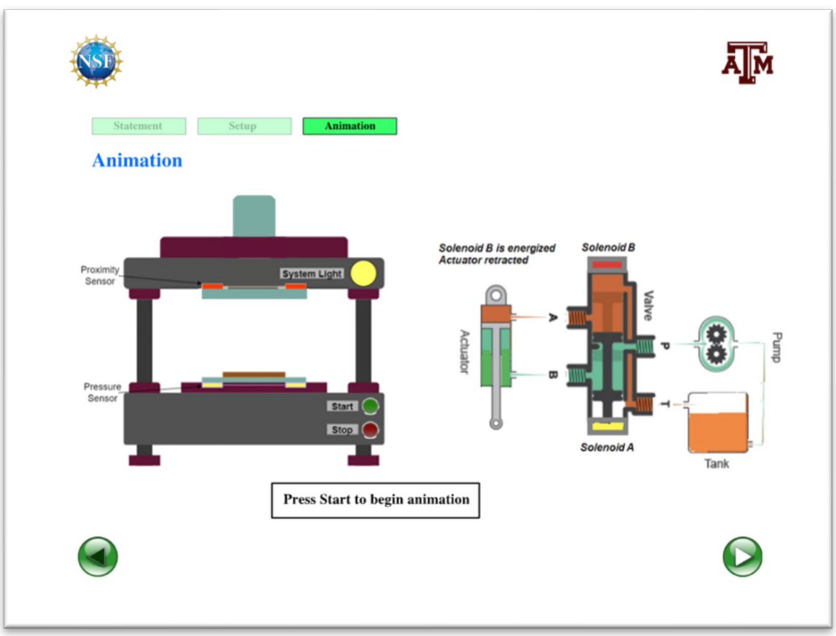


Figure 3. Animation of industrial press in action

The Problem Statement is followed by a Setup Screen that shows the sequence of operations. Figure 2 shows the Setup screen for the industrial press case study.

Following the Setup Screen is an animation of the automated process in action, including processes not normally visible to users. This type of animation helps new engineers to better visualize and understand operating principles. Figure 3 shows the animation for industrial press case study. Users click the Start and Stop buttons on the industrial press image to start and stop the press. The left side of the animation shows that the proximity and pressure sensors are energized as the piston moves up and down. The right side of the animation illustrates the concept of the actuator extending and retracting based on the state of Solenoid A or B (energized or not). The state of the solenoids is determined by the state of the corresponding sensors.

A series of Case Analysis screens follows the animation. Case analysis involves determining inputs and outputs of the process, assigning I/O ports for each input and output, and determining the sequence of events. Figure 4 shows the sequence of events for the industrial press process. Once the I/O addresses and sequence of events have been determined, one can write ladder logic (i.e., a PLC program) to control the process. Figure 5 shows a problem solution screen describing the ladder logic needed.

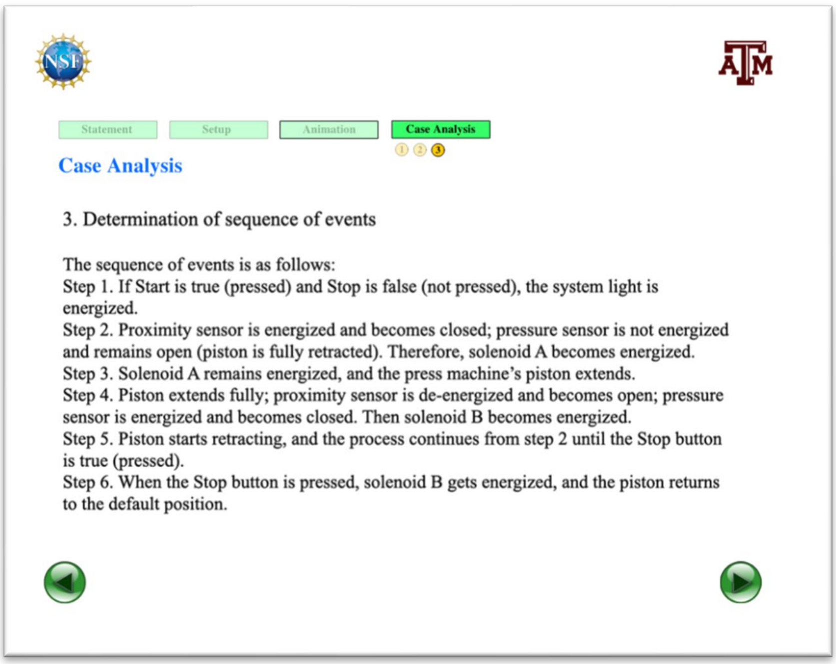


Figure 4. Case Analysis screen showing sequence of events.

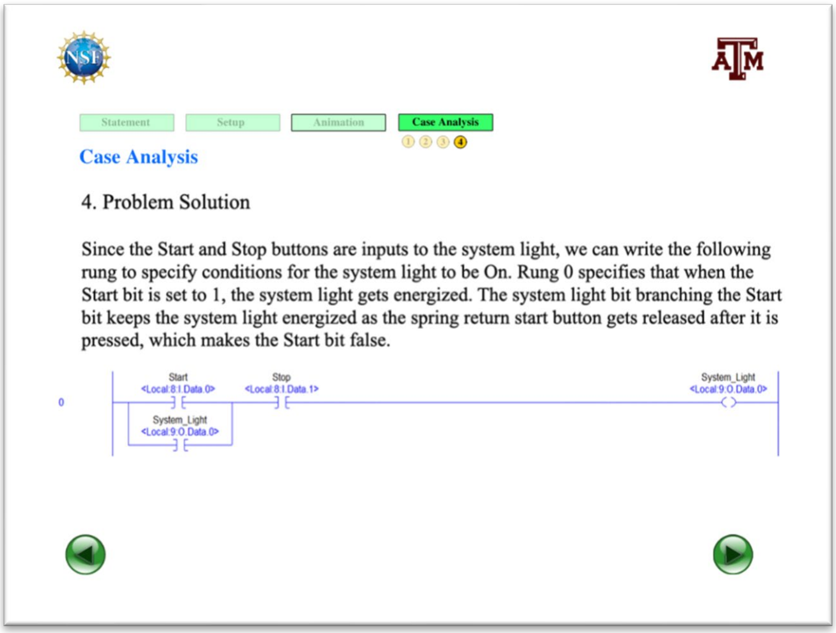


Figure 5. Case Analysis screen showing translation of operations into ladder logic.

A schematic is presented after the Case Analysis stage. The schematic identifies the port and power rating requirements for each input and output (Figure 6) and the electrical interfacing needed to connect all the devices to the PLC (Figure 7). In the physical environment, this looks like wiring the devices to the PLC and other devices such as power supplies and bridging devices. However, there is more to interfacing than simply wiring. One must understand power requirements of devices and the big picture of what needs to happen and how and why things need to be connected a certain way. Mistakes can cause damage to devices or electrical shock. Interfacing devices virtually helps prevent mistakes when interfacing actual equipment.

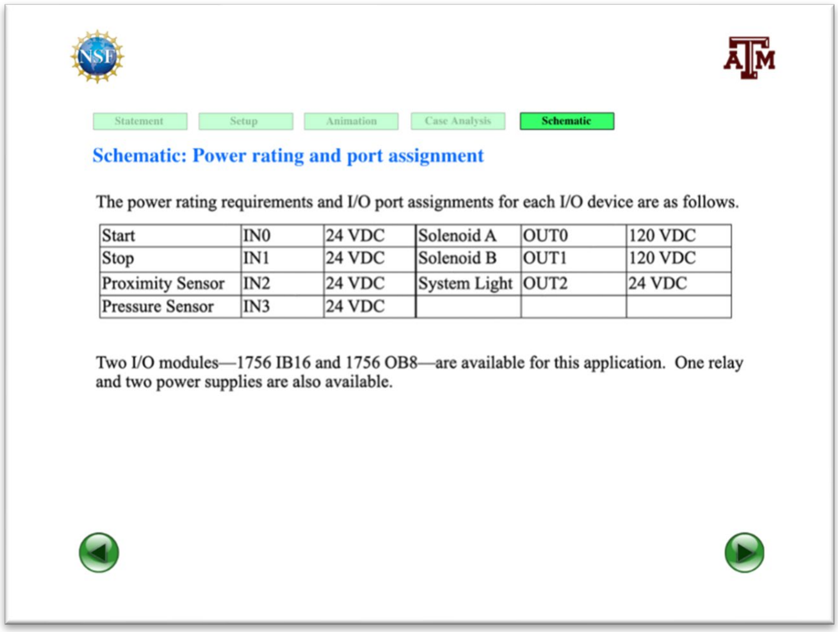


Figure 6. Power ratings and port assignments.

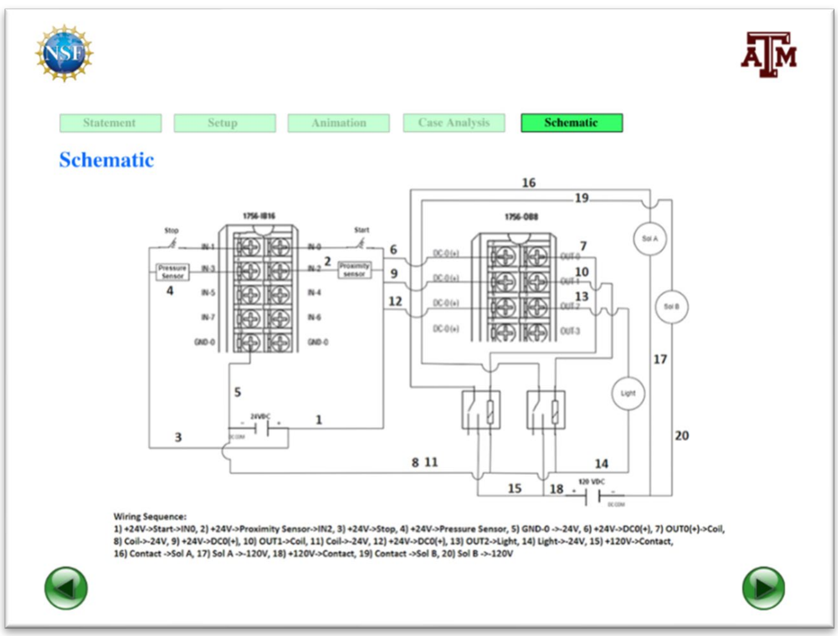


Figure 7. Schematic of interfacing.

At the end of the case study, the learner is given the opportunity to practice interfacing devices to the PLC. The learner can use the mouse to make connections between components (Figure 8) or to click on a component for more details (Figure 9).

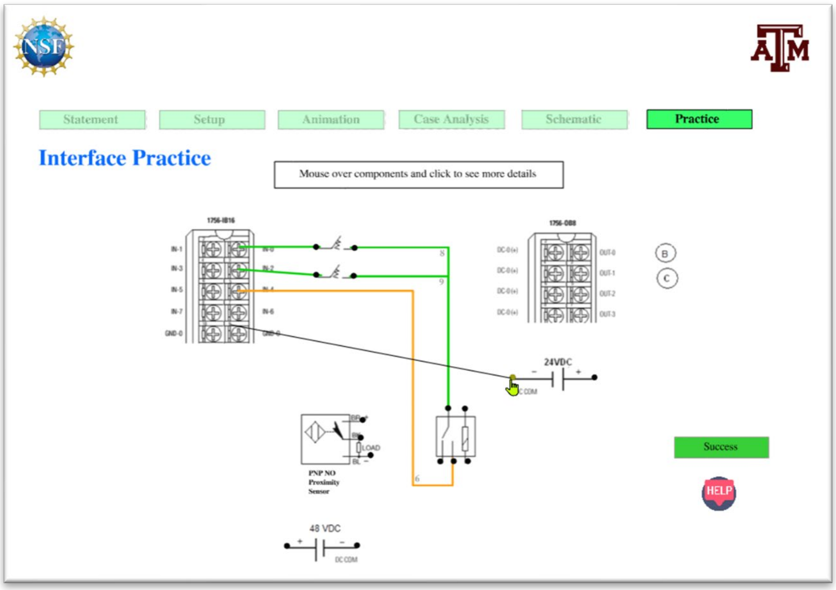


Figure 8. Interfacing practice.

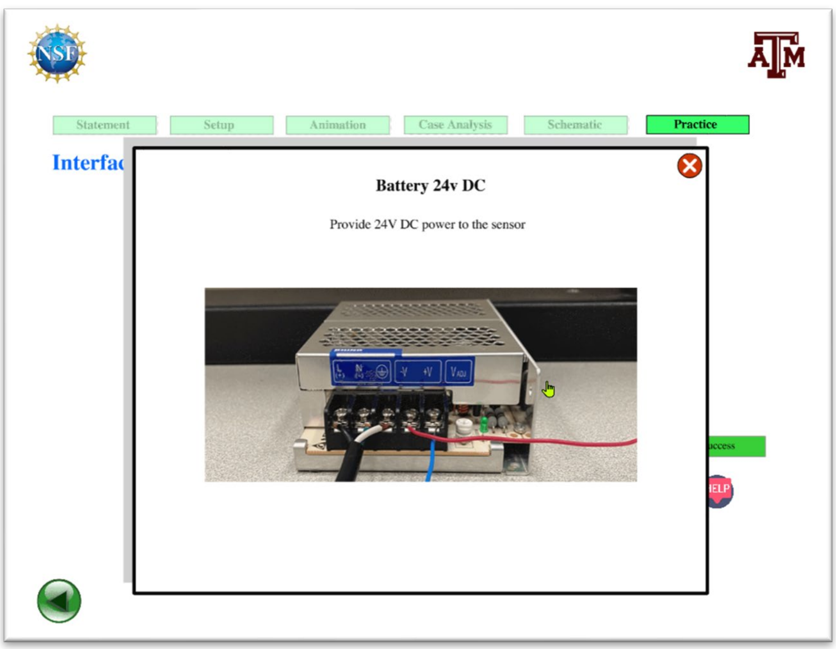


Figure 9. Pop-up help with information about power supply.

4. Evaluation

4.1 Participants and objectives

The widget assembly case study was evaluated by 60 undergraduate students in Spring 2024. This case study was chosen because the evaluation was early in the semester and the students had not learned about interfacing yet. The primary goal of the evaluation was to collect feedback about the case study design.

Students reviewed the case study and 49 of them opted to participate in an opinion survey (participation rate = 81.7%). This survey asked participants to indicate their level of agreement with the following statements using a 7-point Likert scale.

- The animation of the widget assembly line helped me visualize how the widget packaging process works.
- The case analysis—i.e., identification of inputs and outputs, I/O ports, sequence of events, and ladder logic—helped me understand the steps involved in developing a program to control a process.
- The schematic and interface practice helped me understand how to interface the components of an automated system.
- The case study was easy to understand.
- I would like more case studies like this one to help me learn how to automate a process.
- The case study was relevant to my education.

Survey participants also had the opportunity to answer two open-response questions.

- The most helpful thing about this case study was: ___________
- The case study could be improved if: _____________

4.2 Results

4.2.1 Animation

The column chart in Figure 10 summarizes participants' responses to the statement "The animation of the widget assembly line helped me visualize how the widget packaging process works" (n=49).

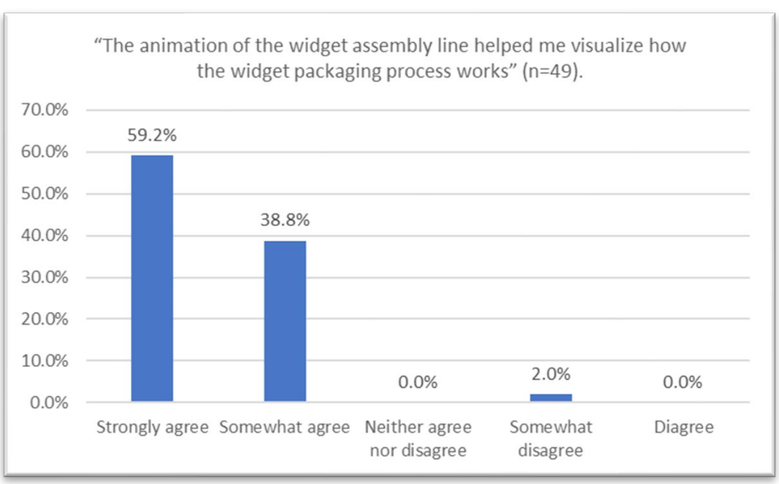


Figure 10. Percentage agreement with statement about the case study animation.

Almost all students (98.0%) agreed or strongly agreed that the animation helped them visualize how the process worked.

4.2.2 Case analysis

The column chart in Figure 11 summarizes student responses to the statement “The case analysis—i.e., identification of inputs and outputs, I/O ports, sequence of events, and ladder logic—helped me understand the steps involved in developing a program to control a process.” (n=49).

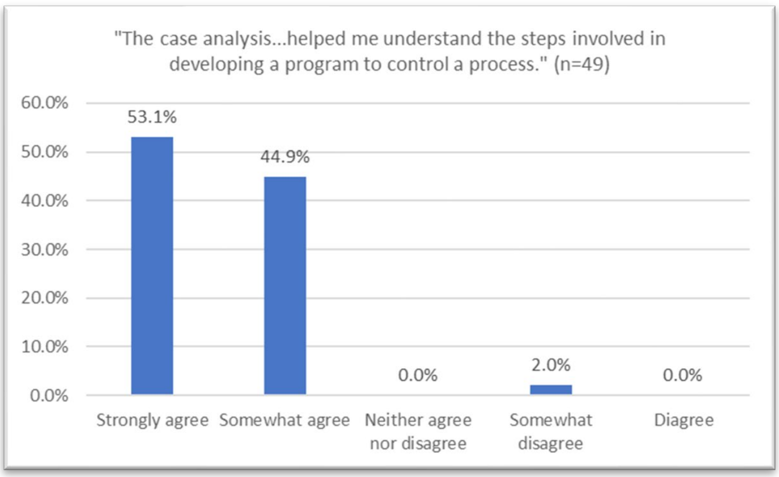


Figure 11. Percentage agreement with statement about the case analysis.

Almost all students (98.0%) agreed or strongly agreed that the case analysis helped them understand the steps involved in developing a program to control a process.

4.2.3 Schematic and interface practice

The column chart in Figure 12 summarizes student responses to the statement “The schematic and interface practice helped me understand how to interface the components of an automated system.” (n=49).

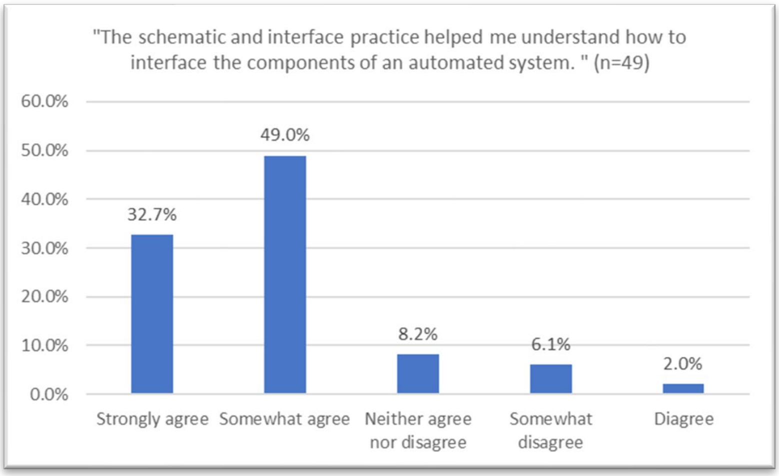


Figure 12. Percentage agreement with statement about the case study schematic and interface practice.

The majority of participants (81.7%) agreed or strongly agreed that the schematic and interface practice helped them understand how to interface the components of an automated system. However, the responses were somewhat less positive than their responses to the questions about the animation and the case analysis; 8.2% were neutral and 8.1% disagreed. A likely explanation is that they had not started learning about interfacing yet at this point in the semester.

4.2.4 Ease of understanding

The column chart in Figure 13 summarizes student responses to the statement "The case study was easy to understand." (n=49).

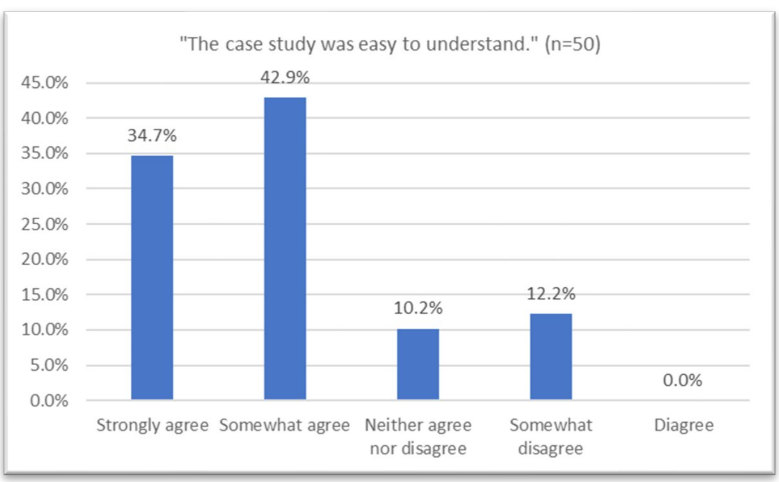


Figure 13. Percentage agreement with statement about case study being easy to understand

The majority of participants (77.6%) agreed or strongly agreed that the case was easy to understand. However, the responses were somewhat less positive than their responses to the questions about the animation and the case analysis; 10.2% were neutral and 12.2% indicated they somewhat disagreed. A likely explanation is that the interfacing component was difficult to understand because they had not started learning about interfacing yet at this point in the semester.

4.2.5 Desire for more case studies

The column chart in Figure 14 summarizes student responses to the statement "I would like more case studies like this one to help me learn how to automate a process." (n=49).

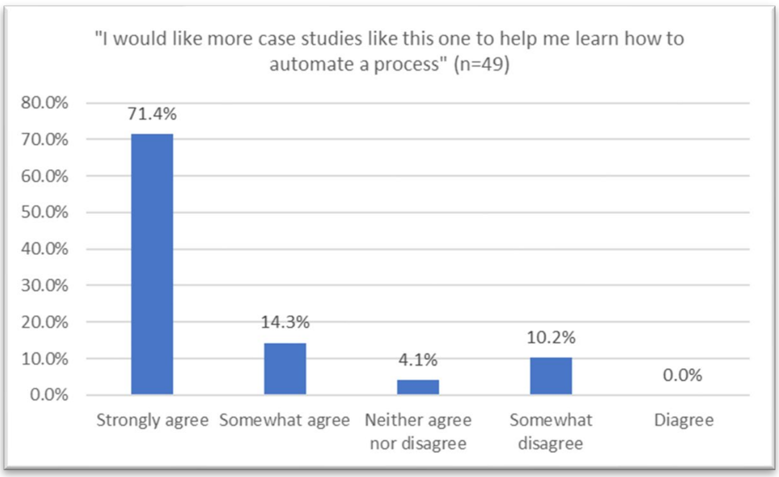


Figure 14. Percentage agreement with statement about wanting more case studies.

The majority of participants (71.4%) strongly agreed that they would like more case studies like this one. Another 14.3% agreed, for a total of 85.7% that agreed or strongly agreed.

There were also a few that were neutral (4.1%) or somewhat disagreed (10.2%). To understand why these participants would not like more case studies like this one, we looked at these participants' responses to the open-ended question about how the case study could be improved. These participants made comments such as 1) the case study should be more interactive; and 2) the interfacing diagram and the interfacing practice were confusing.

4.2.6 Relevance to education

The column chart in Figure 15 summarizes student responses to the statement "The case study was relevant to my education." (n=49).

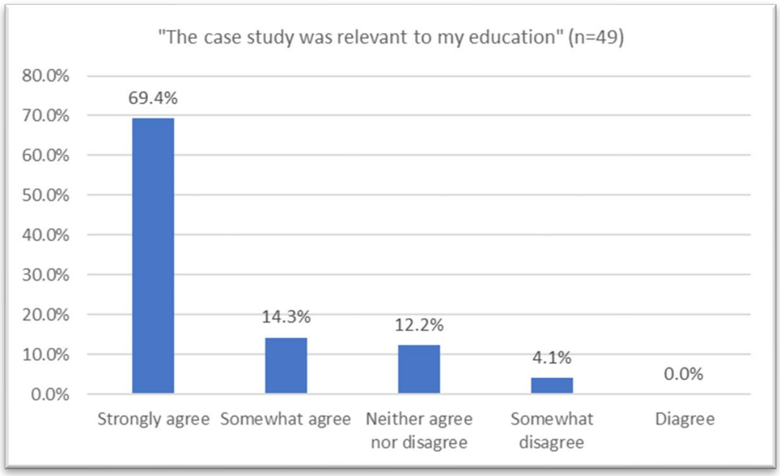


Figure 15. Percentage agreement with statement about relevance of case studies.

The majority of participants (69.4%) strongly agreed that the case study was relevant to their education. Another 14.3% agreed, for a total of 83.7% that agreed or strongly agreed.

There were also a few that were neutral (12.2%) or somewhat disagreed (4.1%). To understand why participants did not agree that the case study was relevant to their education, we looked at these participants' responses to the open-ended question about how the case study could be improved. These participants commented that 1) the case study should be more interactive; 2) the instructions for the interfacing practice were not clear; and 3) they needed to be taught more about interfacing before beginning the activity.

4.2.7 Most helpful features

Below is a summary of predominant themes in participants' responses to the question "The most helpful thing about this case study was …"

- *Visuals*. Many participants found the visuals in the case study to be helpful, including the pictures, animations, diagrams, and step-by-step presentations. These visuals helped them to understand the concepts being taught and to see how the different components of the system worked together.
- *Interactive elements*: Some participants noted that the interactive elements of the case study—such as the interface practice—helped them to learn in a more hands-on way and to test their understanding.
- *Clarity and simplicity*: Participants found the case study to be easy to understand and follow, even if they had no prior experience with PLCs.
- *Breakdown of complex topics*: The case study was also helpful in breaking down complex topics into smaller, more manageable pieces. This made it easier for participants to learn and understand the material.
- *Real-world application*: Some participants noted that the case study helped them better understand how PLCs are used in real-world applications.

Overall, the most helpful thing about the case study seems to be the variety of learning styles that it can accommodate. With its visuals, interactive elements, clear explanations, and breakdown of complex topics, the case study helped participants learn and understand the material.

4.2.8 Areas for improvement

Below is a summary of participants' responses to the question "The case study could be improved if …"

- *Clarity of explanations*: Several participants found the problem solution and schematics confusing. Some requested simpler instructions and shorter explanations to aid understanding.

- *Visualization and interactivity*: Participants requested a zoom function for the schematic and interface practice for better readability. Some suggested showing real pictures alongside the schematics for better visualization. One participant proposed an interactive task at the beginning to familiarize users with the interface. Another participant mentioned an issue with understanding the wiring to the relay and components.

- A bug was reported related to the "Success/Wrong connection" indicator flashing during the interface practice.

- Additional suggestions included 1) Show an additional industry example alongside the case study animation; 2) Go more in-depth on sensor programming and how they work together; 3) Consider a pop-up window for the schematic in the practice section for easier reference; and 4) Allow easier navigation between tabs in the case study.

4.3 Discussion

Overall, 98.0% of the 49 participants agreed that the case study's animation and case analysis components helped them to understand the steps involved in automating a process. Somewhat fewer agreed that the schematic and interface practice components were helpful (81.7%) and that the case study was easy to understand (77.6%). This slight decline is most likely because the participants had not learned about interfacing yet at the time of the case study evaluation took place.

A strong majority of participants agreed that they would like more case studies like this one (85.7%) and that the case study was relevant to their education (83.7%). Most who disagreed or had a neutral response made comments about the interfacing portion of the case study such as the instructions needed to be clearer and/or they needed to know more about interfacing before beginning the activity.

Many participants commented that the pictures, animations, diagrams, and step-by-step presentations were helpful to their understanding. Suggested improvements include clearer instructions and explanations and a zoom function to make the details in the schematic easier to see.

Most suggestions for improvement understandably center around the interfacing activity. We believe these concerns will be greatly alleviated once the participants have had the opportunity to learn more about interfacing components. It is encouraging that even with their lack of prior knowledge about interfacing, a strong majority of participants found the case study to be a helpful learning experience. It should also be noted that while being exposed to a case study at such an early stage of learning was a stretch, participants gained a broad overview of the process of building an automated system. The experience helped them see what they will learn in the rest of the course and how it all fits together.

5. Future work

Future work will include 1) fix bugs identified during the evaluation; 2) make user interface instructions clearer; 3) solicit input from industry, instructors, and current/former students about additional case studies to develop; 4) create more case studies; and 5) evaluate transfer of learning by varying the sequence of operations in the case study.

6. Acknowledgements

This material was supported by the National Science Foundation's Improving Undergraduate STEM Education (IUSE) Program (award no. 2044449). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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