
AC 2011-1996: DESIGN OF PROBLEM SOLVING ENVIRONMENT FOR AUTOMATED SYSTEM INTEGRATION EDUCATION

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Design of Problem Solving Environment for Automated System Integration Education

Abstract

Research suggests that realistic practice using authentic learning environments leads to better transfer of skills. Based upon input from industry engineers with expertise in designing and building automated systems, a problem solving environment (PSE) for automated system design has been developed. The PSE provides a virtual environment for building, testing, and validating designs for a process to be automated.

This virtual environment allows students to design systems to automate manufacturing processes. Students may build systems to automate either a single type of process (continuous, discrete, or batch) or a combination of processes (hybrid). The user is presented a toolbox containing equipment and building blocks of automation such as sensors and actuators. The PSE supports students in design problem-solving activities such as (1) reviewing the problem, (2) understanding the process to be automated, (3) line balancing, (4) layout, (5) simulation, and (6) cost analysis.

This paper will describe the design of the PSE. Future plans include conducting evaluations with students and adding student modeling to provide adaptive support for students.

Introduction

Automation has a profound effect on the way we do work. A U.S. Census Bureau report notes that yearly exports in the flexible manufacturing category (equivalent to industrial automation) were \$19.44B in 2006, a 10% jump from \$17.61B in 2005¹. Moreover, monthly exports in the flexible manufacturing category were \$4.06B in March 2008, a 0.5% jump from \$4.04B in March 2007². This trend is likely to continue to increase as the manufacturing sector continues to transform to a high tech, less labor-intensive and value added industry using advanced automated systems.

Integrating the components of an automated manufacturing system requires knowledge about the various mechanical and electrical devices available to make up the system—including their functions, power requirements, and specific characteristics—and the ability to write programmable logic controller (PLC) programs to orchestrate and synchronize the process being automated. It is a complex cognitive skill, and often there is no course available that teaches it. In addition, some colleges do not have the equipment resources needed to provide hands-on experience with automated systems. Consequently, new automation and control engineers are often not fully prepared to perform system integration tasks. Readily available instructional materials are needed to better prepare new engineers for these challenging tasks.

Relatively few instructional technology development efforts have focused on the area of automated system design and education. However, there are two related projects related to control of automated systems using PLC programming. For example, LogixPro 500 (<http://www.thelearningpit.com/>) employs animated educational simulations of processes, such

as traffic control and batch mixing, to show how a ladder diagram relates to an automated process. Students can start and stop the animations, and study the corresponding ladder diagram for certain conditions or cases.

The author has developed an Integrated Virtual Learning System for Programmable Logic Controller (Virtual PLC) under an NSF grant. This system uses a combination of animations, simulations, intelligent tutoring system technology, and games to teach about programmable logic controllers. As with LogixPro 500, students can view animations of processes and study the corresponding control programs. In addition, they can use a ladder logic toolkit to write and test their own control programs. In every evaluation so far, students have made statistically significant learning gains as a result of using the system, and rated the modules positively in terms of ease of use and understanding, clear objectives, amount of interaction, ability to motivate, relevance, and pace^{3,4,5}.

Both of these systems are good examples of how technology can be used effectively to teach PLC programming. However, a PLC is just one component of an automated system. Technologies are needed to enable students to learn how to integrate multiple components to form an automated manufacturing system, develop the associated control logic, and run the system. In addition, research suggests that realistic practice in authentic learning environments leads to better transfer of skills^{6,7}.

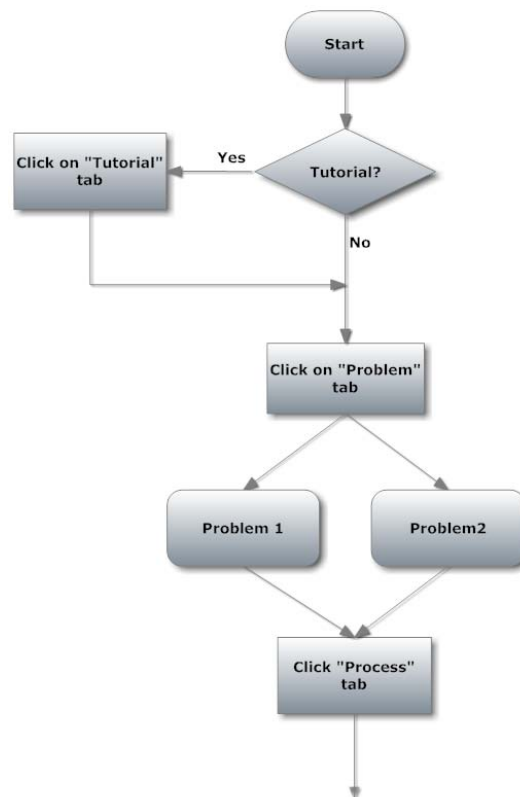


Figure 1(a). Flow diagram for PSE for design of automated systems (top section)

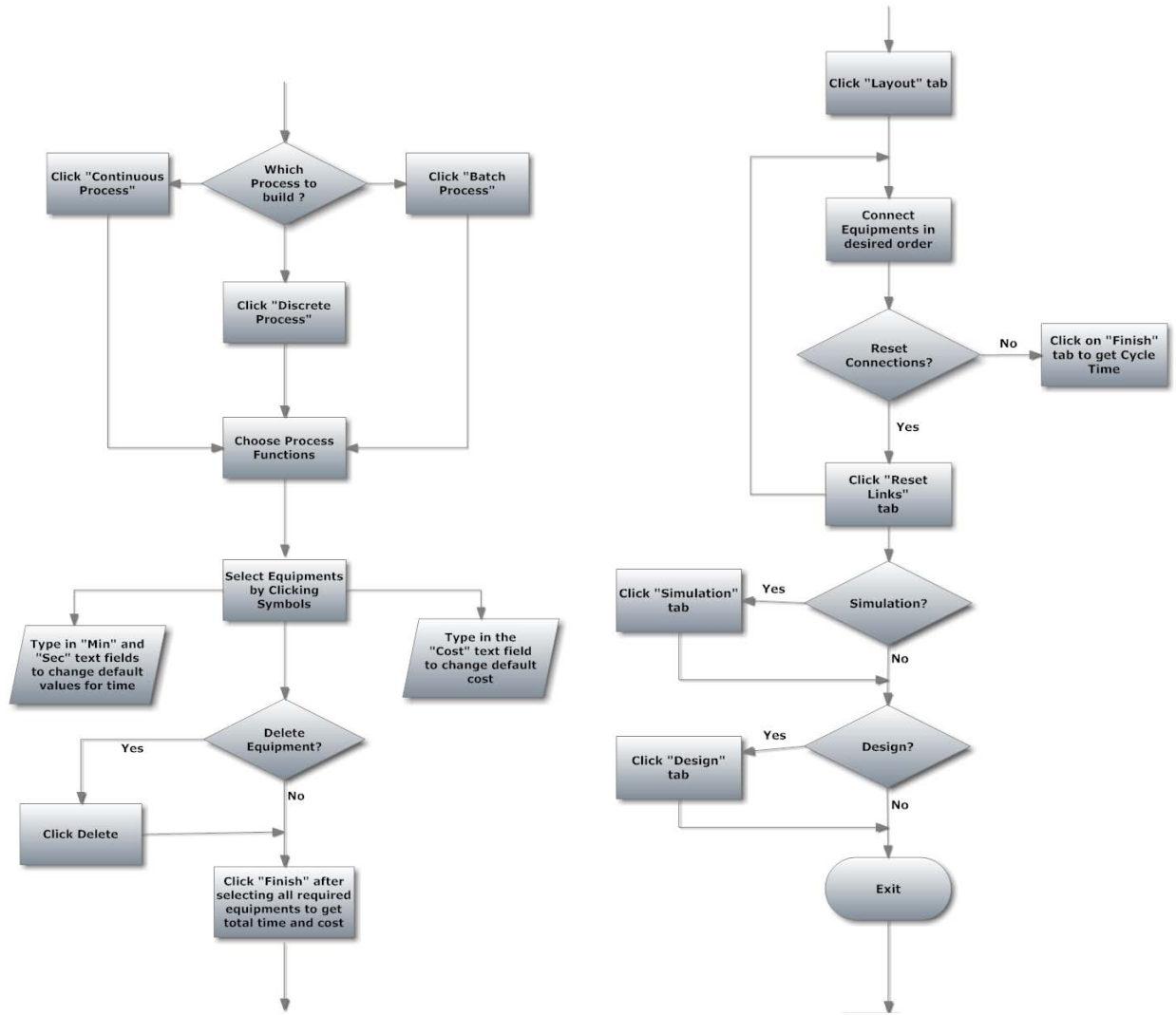


Figure 1(b). Flow diagram for PSE for design of automated systems (middle and bottom sections)

This paper describes a problem-solving environment for automated system design. This virtual environment was developed based on input from industry engineers with expertise in designing and building automated systems. It allows students to design systems to automate manufacturing processes. Students may build systems to automate either a single type of process (continuous, discrete, or batch) or a combination of processes (hybrid). The user is presented a toolbox containing equipment and building blocks of automation such as sensors and actuators. The PSE supports students in design problem-solving activities such as (1) reviewing the problem, (2) understanding the process to be automated, (3) line balancing, (4) layout, (5) simulation, and (6) cost analysis. Figure 1 shows a flow diagram for this PSE.

Figure 2 shows the opening screen from the PSE for continuous processes. The opening screen includes a menu with seven buttons corresponding to various options. The user can choose to go to the tutorial or start working on a problem by clicking the Problem button.

Figure 3 shows a screen from the tutorial. The tutorial explains how to use the PSE, including a typical process flow towards achieving a desired design goal. The tutorial provides very detailed page-by-page instructions and illustrations showing the user exactly what to do after each action. Technical information about the manufacturing processes and examples are also provided. Users can exit the tutorial and return to the menu any time by clicking the Exit button.

When users click the Problem button, they are allowed to choose from several problems. The Problem screen provides background information and the goal for each available problem. For example, Figure 4 describes a problem related to automating soap manufacturing.

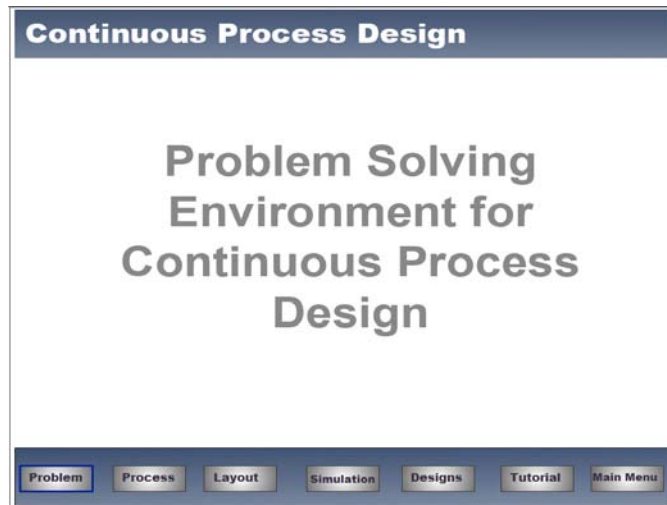


Figure 2. PSE for hybrid process design

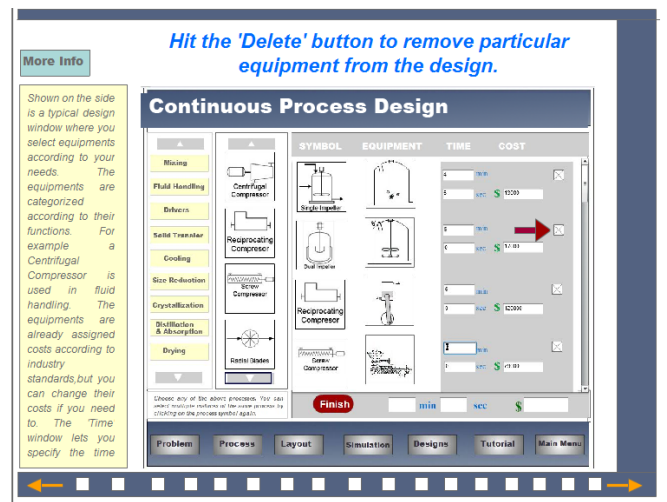


Figure 3. Tutorial



Figure 4. Problems page

When users click the Process button from the menu, they are allowed to choose different machines or equipment for various processes that might be included in their automated system. Processes available include mixing, fluid handling, cooling, solid transfer, and several others. For each process, various types of equipment may be selected.

The following sections will provide an example of using the PSE to solve the following problem: A customer asks you to design a chocolate kisses production line. Requirements include: 1) production rate of one million kisses/hour, 2) \$75 million dollar budget and 3) delivery within nine months. A chocolate kiss consists of: chocolate, sweetener, flavors and wrapper.

Major steps of the chocolate kisses production process are as follows:

1. Roast the cocoa beans.
2. Winnow the beans to separate the nibs from the shells.
3. Mill the cocoa nibs to form chocolate liquor.
4. Extract cocoa butter from chocolate liquor.
5. Pulverize cakes of chocolate.
6. Blend ingredients to form chocolate.
7. Feed the chocolate into molds.
8. Wrap the chocolate kisses.

For Step 1, roasting the cocoa beans, the user would choose appropriate equipment from the Heating process group (Figure 5). There are two types of equipment/machines to choose from: Fired Heater – Box Type and Fired Heater – Cylinder Type. When the user selects a machine (in this case, Fired Heater – Box Type), the symbol for that machine is loaded into the field labeled “Symbol” and also sent to the Layout page (described below). In addition, a cost for that machine is loaded into the corresponding Cost field. The default cost is based on industry standards, and can be adjusted by the user as needed. The “min” and “sec” time values are set to zero by default. Users can change the default values by typing in new values.

Similarly, for Step 2, winnowing, the user would choose equipment from the Separation process group. For this process, the user may choose from several types of equipment, including

centrifuge – solid bowl, disk separator, cyclone separator, and filters. The user chooses centrifuge – solid bowl and the cost for that equipment (\$151,000) is loaded into the Cost field.

The user continues selecting equipment until equipment, cost, and time has been specified for all steps in the chocolate kisses manufacturing process. Deleting a symbol removes all the instances of the symbol from the Process and Layout pages. When users are done selecting equipment, they click on the Finish button. The Finish button calculates total cost and time for all the processes and displays them in the corresponding boxes.

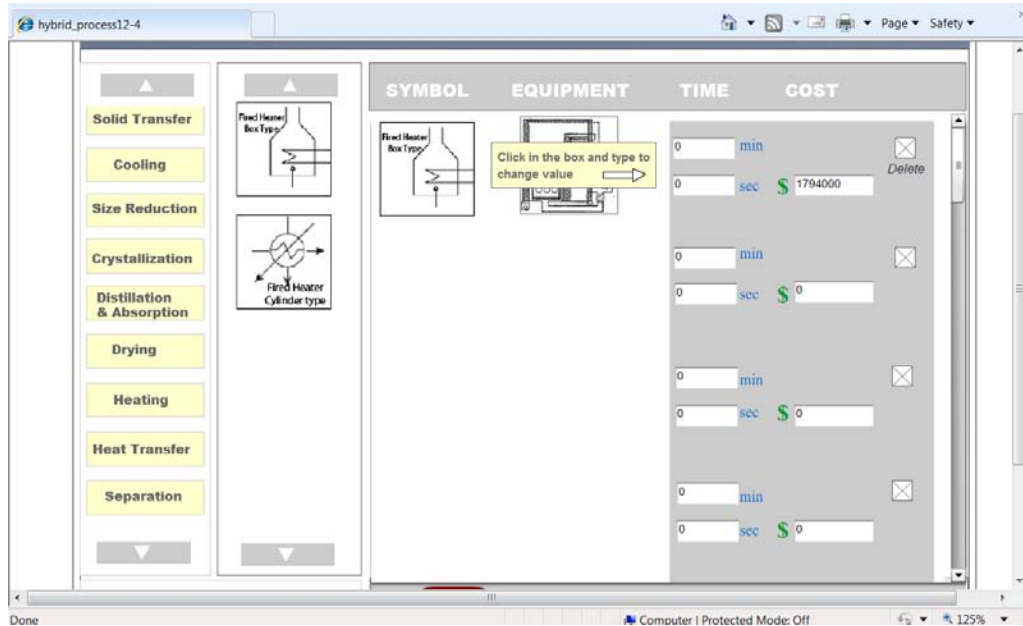


Figure 5. Process page showing available machines for heating process

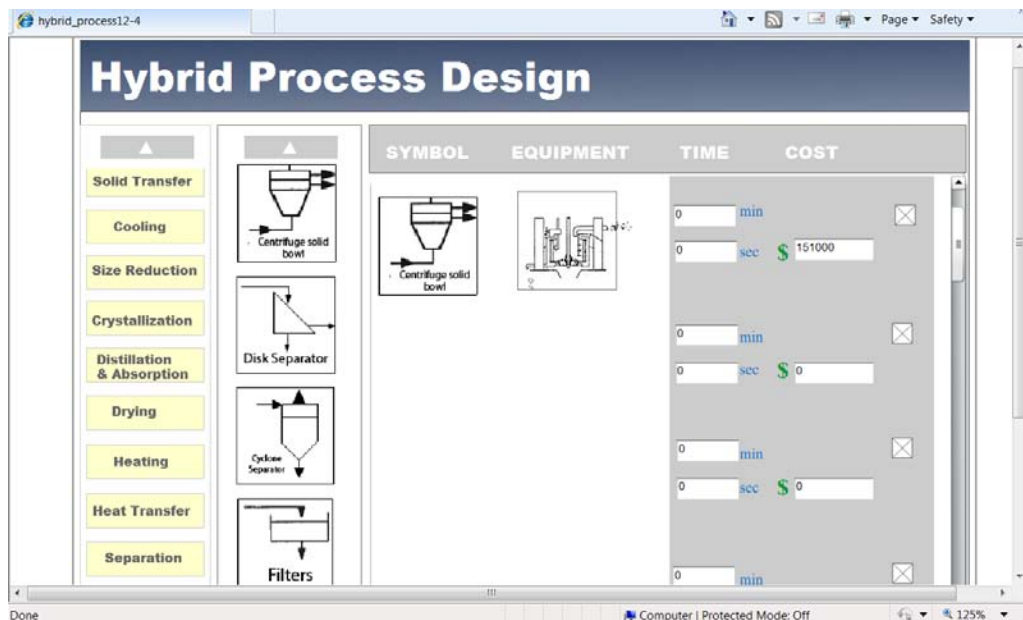


Figure 6. Process screen showing available machines for separation process

After users finish selecting machines and specifying time and cost for each individual machine, they go to the Layout page. The Layout page contains the symbols that were selected on the Process page. Users can arrange the symbols and make interconnections according to the process requirements. Each symbol has an associated connection menu that can be used to connect it to other symbols or to remove it (Figure 7). A time window pops up whenever the mouse hovers over a symbol. All the time values input in the process page are displayed. Time values can also be changed by typing in new values. After finishing the connections and adjusting times, users can click the Finish button (Figure 8). The program calculates cycle time for the process by entering all the time values in an array and then running a sorting algorithm to find the largest value, which is then displayed in minutes and seconds in the cycle time text fields. Also, when the Finish button is clicked, a snapshot of the layout is saved as a JPG image for further use on the Design page.

The Simulation page (Figure 9) shows users a very basic simulation of the entire process. It consists of simple animations depicting functions for individual equipment. Users can also make or break connections on the Simulation page.

The Designs page (Figure 10) lets users see and review all the designs they created in a single session. Each design is portrayed as a button. Users can click on a button to review the layout of the corresponding design.

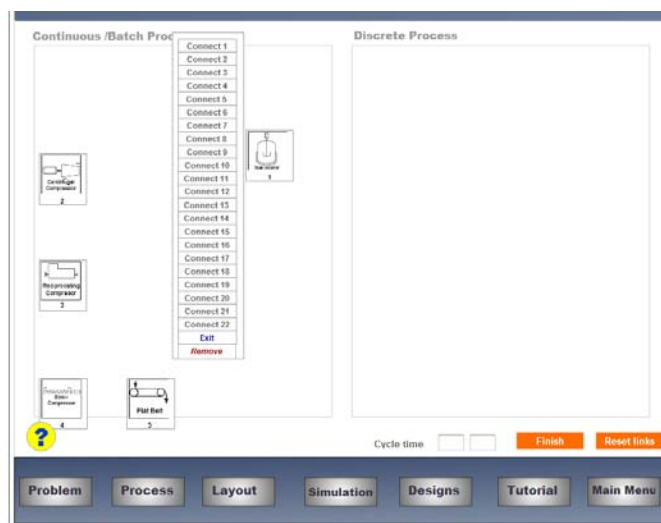


Figure 7. Layout screen without connections

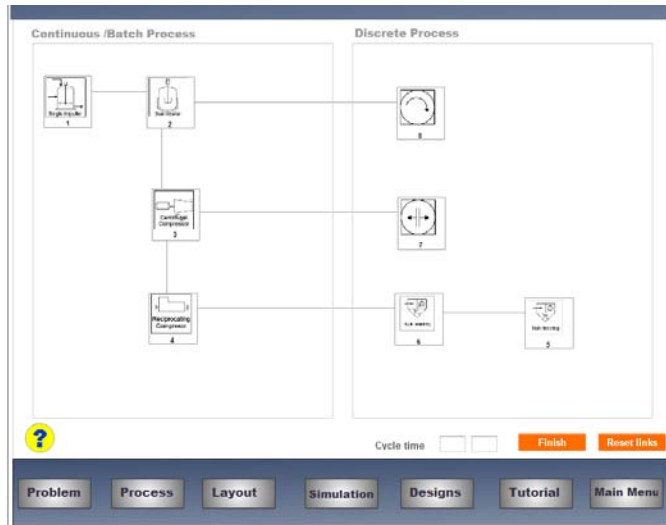


Figure 8. Layout screen with connections

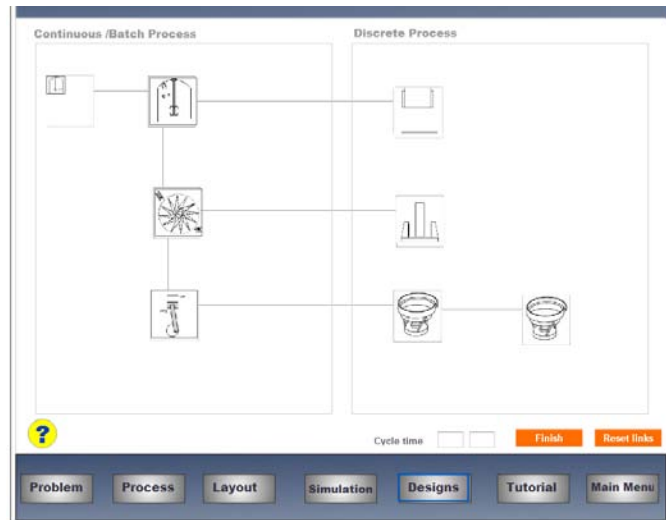


Figure 9. Simulation screen

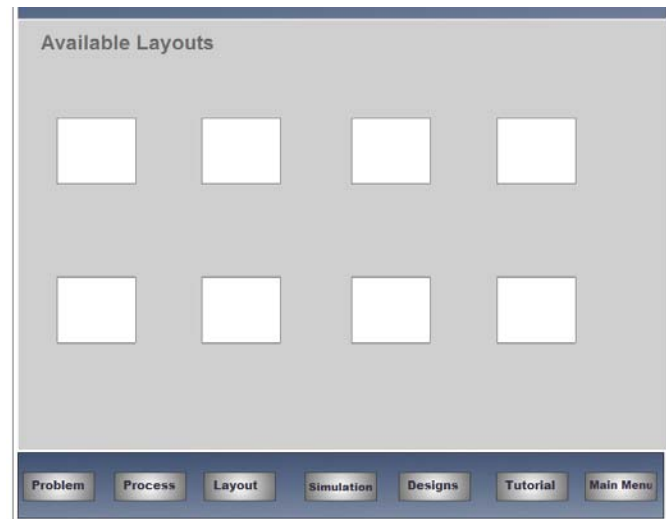


Figure 10. Designs screen

Evaluation

In developing the case studies and problem solving environments, we have met with engineers from our industry collaborators. They helped to identify the general principles and content used in the case studies, and to confirm that the developed materials were appropriate, realistic, and technically accurate. Formal evaluations of developed materials with students will be conducted in Spring 2011.

Conclusion and Future Directions

This paper describes the design of a problem solving environment for automated system design. This virtual environment allows students to design systems to automate continuous, discrete, and batch manufacturing processes, and combinations thereof (hybrid processes). Future plans include conducting evaluations with students and adding student modeling to provide adaptive support for students. So for example, a new learner may receive hints to help him or her to recall the steps that need to be automated. As the learner is more skillful, the PSE will gradually provide fewer hints.

Acknowledgements

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