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# A WEB SITE TO SUPPORT ACTIVE STUDENT LEARNING IN PROCESS CONTROL

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## Abstract

In this paper, a novel WEB site is described that provides interactive learning for undergraduate process control education. The site engages the students through three modes that enable students to learn on their own schedule and at their own pace. First, the *Interactive Learning Modules* provide questions that follow the topic sequence in a standard course. The questions begin with simple, yet essential, terminology and definitions; then, they progress to engineering applications. Students can request hints for many questions, and they receive feedback for correct and incorrect answers. Second, more complex issues are addressed in *Tutorial* questions and answers. Third, *Instrumentation Notes* provide resources for problem-based learning exercises. The paper discusses how this material can be integrated into a course on process control. Those interested can visit the site, http://www.pc-education.mcmaster.ca, which is open for all instructors and students.

## 1. Introduction

The power of digital computation has had a major, positive influence on engineering education. The most important application of digital computers continues to be facilitating time-consuming computations, enabling students to concentrate on principles. The use of simulation is particularly effective in process control education because of the complex behaviors of closed-loop systems. This need has been filled by several packages designed for education [1,2,3].

Recently, new opportunities for applying computers have become available because of the WWW. Perhaps the most common use of the WEB is for managing course materials; i.e., posting course outlines, announcements, assignments and solutions. In addition, some courses require students to perform quizzes and submit assignments via



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the WEB, which facilitates grading and record keeping. These course management functions are well addressed by conventional tools, such as WebCT [4]. The site described here could be called by any Web-based course-management system.

In spite of many impressive achievements, we have not yet tapped the full potential of digital computation in engineering education. This paper presents a novel use of computers in education that emphasizes active learning, rather than computational methods or course management.

## 2. Educational Objectives

Educational objectives for essentially any engineering course can be presented using the three categories developed by Rugarcia, Felder, Woods, and Stice[5]. These categories highlight the importance of life-long learning skills to complement the ever-important technical knowledge. An example of an objective for each category is given in the following.

- **Attitudes**: Students must accept responsibility for their education, including using all resources and requesting assistance when needed.
- **Skills**: Students need to be capable learners; they should be able to set objectives, learn and teach material, and evaluate their own learning.
- **Knowledge**: Students need mastery of a substantial body of technical knowledge to be able to practice their engineering discipline.

## 3. The Self-Study Gap

Many resources are available for a typical university-level course, and there is no reason to replicate good aspects of these resources. Strengths and weaknesses of existing approaches to university education are summarized in Table 1. Much factual knowledge is readily available in textbooks and supplemental information available in libraries and WEB resources. In addition, simulation software and laboratories provide students with experiences in the application of process control. Finally, the essential personal contact is provided during classes, tutorials, and office hours.

However, the current resources have significant weaknesses as well. One key area for improvement is student self-study through active learning; the value of active learning is well accepted[6,7]. Self-study is important because students will become practitioners without access to the instructors, so that they need to build *life-long learning* skills. Since many students have not developed self-study skills, they rely on the instructor to provide guidance through classes and assignments. A symptom of this situation is perhaps the most common student request: “We want more sample problems, with solutions.” The purpose of the WEB site is to provide (1) specific knowledge related to process control, (2) more importantly, good examples of self-directed learning. Students can see numerous examples of critical thinking, visual displays of concepts, and questions for self-testing.

**Table 1. Summary of Learning Resources**

| Learning Resource | Strengths | Weaknesses |
|---|---|---|
| Textbook | • Detailed, complete exposition of topic<br>• Integrated, consistent coverage<br>• Prepared for student (age, preparation, etc.) | • Formal, complex presentation<br>• Not interactive<br>• Expensive, which limits additional background materials, color images, etc. |
| Simulations | • Learning based on experience<br>• Rapid, visual feedback<br>• Ability to investigate | • Usually does not represent realistic systems<br>• Investigations severely limited by simulator design |
| Library and WEB | • Resources for problem-based learning<br>• Alternative presentations | • Nearly every opinion presented somewhere, without critical comparison<br>• Often difficult to find materials |
| Laboratory | • Contact with real equipment and computing interfaces | • Time, safety and expense limit complexity of processes<br>• Few disturbances and little noise typically exist. |
| Class | • Informal introduction to material<br>• Students questions are addressed immediately | • Most students do not/cannot participate |
| Tutorial | • Open-ended issues encountered<br>• Immediate feedback to students | • Complexity limited by time available |
| Office hours | • Best possible interaction | • Few students use the option<br>• Resources are not available to accommodate all students |
| Assignments | • Complex issues encountered with time to investigate and seek assistance | • Not all students complete as individual<br>• Feedback is delayed |

The WEB site has three major components to help students with different learning challenges: Interactive Learning Modules, Tutorial Exercises, and Instrumentation resources. Each is discussed in the following sections.

## 3.1 Interactive Learning Modules (ILM)

The Interactive Learning Modules help students master the basic concepts. Before progressing to complex problems, students need to clearly understand the learning goals of the subject, they must master the terminology, and they should be able to explain principles verbally and apply them to simple problems arising in engineering practice and everyday life. The challenge is not to provide more information, but to engage students in a unique mode of learning that builds a solid understanding while providing good examples of learning techniques. To provide interaction and evaluation of student answers, most of the questions are formulated to elicit a short answer, usually either a multiple choice or true/false. Also, many questions provide a hint button that encourages students to "stick with" the problem solving activity and not select an answer prematurely. Feedback is given for both correct and incorrect answers. Naturally, the students can use the information from the incorrect answer in selecting a second choice. Where appropriate, the student is guided to reference materials for more complete explanations and review. In some answers, short derivations and calculations are provided.

### 3.2 Tutorial Exercises

Many learning goals require more complex questions and responses than can be accommodated with the ILM format. Therefore, Tutorial Exercises are provided to provide guidance on more in-depth learning. They provide complex analysis, modelling, design and evaluation questions that require some time to prepare a complex answer beyond a multiple choice, and in some cases, use of outside resources. Complete solutions are provided, and discussions on the relevance and importance of the topic are integrated with the solutions. Also, common mistakes are discussed. These are the "sample problems" that students usually seek; however, the students are encouraged to complete the relevant ILM before proceeding to the tutorial questions, so that they have a good basic understanding of the concepts.

### 3.3 Instrumentation Resources

Every engineering course should reduce theory to physical reality, including related process equipment. Typically, instructors give instrumentation too little attention in university education, and when it is covered, they tend to teach details of specific sensors and valves. A contrasting, and in our opinion better, approach involves teaching key features that enable engineers to match equipment to applications. For example, key sensor features include accuracy, reproducibility, range, linearity, and process conditions. Key valve features include pressure drop, characteristic, tight shutoff, and fluid type. Naturally, reliability and cost are always factors. The Instrumentation Notes provide guidance on the general factors that all students need to know and examples of good practice. Also, students are able to access a wide array of reference material from other sites on the WWW.

## 4. General Site Layout

The WEB site is intended for use after the students have gained knowledge through reviewing reading materials and participating in classes. Thus, the student encountering the site has some initial knowledge, which in such a complex topic is expected to have gaps and errors. The site is accessed through a single home page, from which the student branches to the three components, as shown in Figure 1.

Students should begin using the WEB materials immediately after encountering the topic in their readings and classes. In the design proposed here, students are

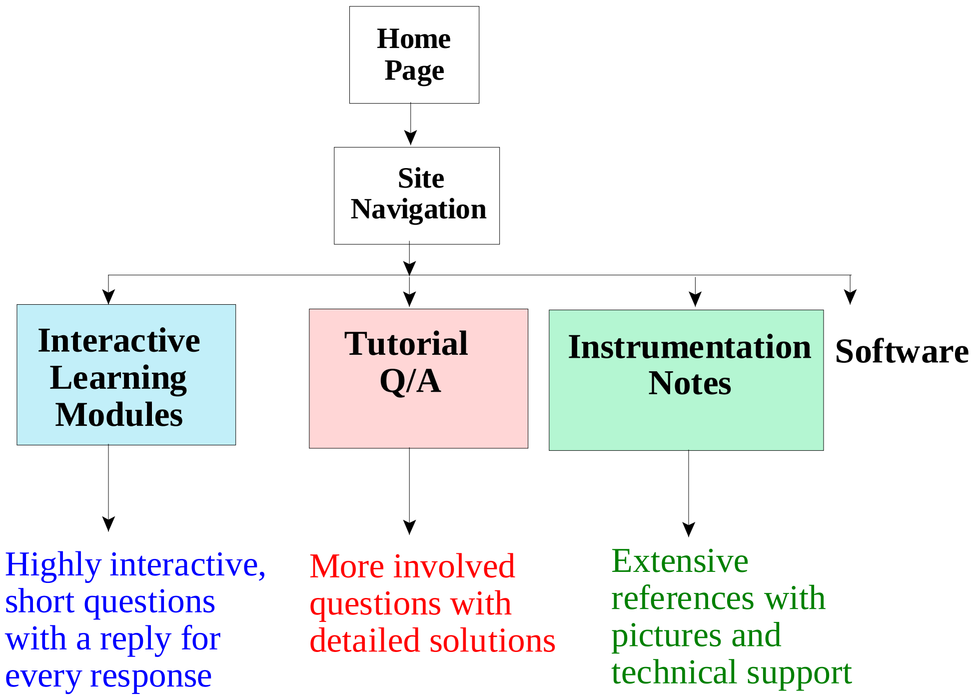



Figure 1. Structure of the Web site.

encouraged to perform the exercises without the pressure of grades, and they can return to the modules as often as needed. Thus, the students can follow a self-paced program of self-directed learning.

The modules are designed to follow the topic sequence in a typical course. Specifically, the process control topics are selected to complement one of the recent process control textbooks[8], but the site could be used by students using any of the standard undergraduate textbooks in the field. Recall that the site is open to everyone, not just in courses that have adopted a specific textbook.

## 5.0 Content of Each Component

### 5.1 Interactive Learning Modules

As shown in Figure 2, each topic or chapter in the Interactive Learning Modules has a number of questions grouped into three categories; *Check Your Reading*, *Study Questions*, and *Thought Questions*. The structure of the site is "broad and shallow", which facilitates easy navigation. The following examples are typical of the site contents, but the "touch and feel" can be experienced only through visiting the site.

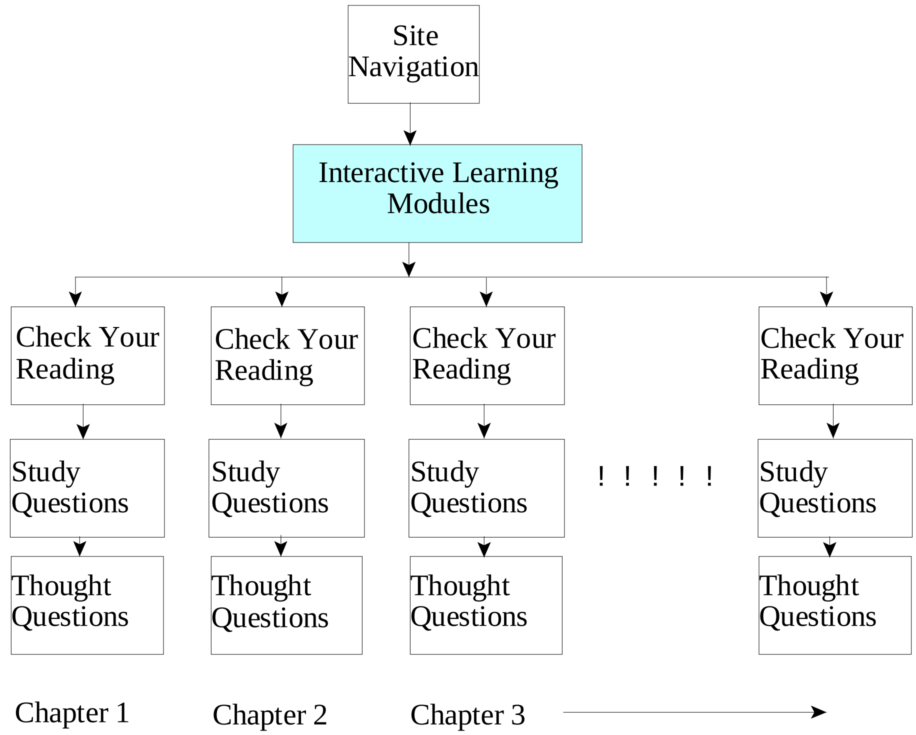



Figure 2. Structure of the Interactive Learning Modules.

**Check Your Reading**: Students begin a topic with *Check Your Reading* questions to ensure comprehension of basic terminology and concepts. The students should be able to find the answers to these questions through careful reading of the relevant reference material. Since feedback is provided immediately on all student answers (correct and incorrect), students can master the basics before advancing to more complex problems. While these questions might appear trivial to instructors, few students can complete all of these questions successfully on the first try. Some examples of *Check Your Reading* questions follow, with the correct answer noted by a ☺ , which naturally, is not shown on the WEB to the student.

1. To apply the process reaction curve, the process response must (see Figure3)

☐ be exactly first order.
☐ be exactly first order with dead time.
☐ have a positive gain.
☐ have an overdamped, monotonic step response. ☺

Question 1 requires the student to understand the assumptions and derivations used in developing the equations for the process reaction curve method. More importantly, the student needs to understand that the assumptions need not be satisfied *exactly* when fitting models useful for most applications in process control. This type of question requires the student to look past the calculations to understand the basis for the calculations.

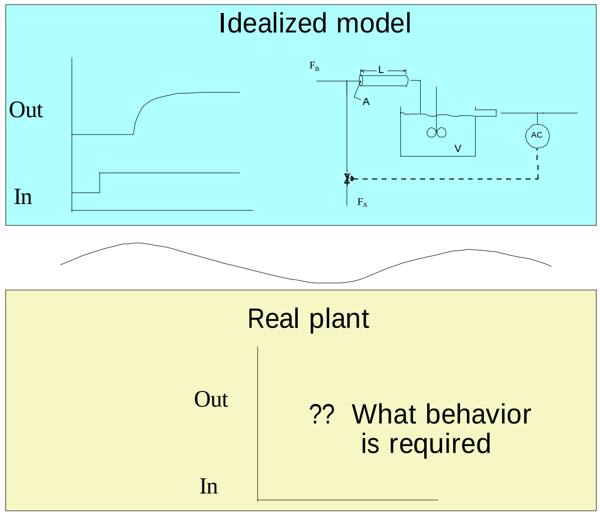



Figure 3. Schematic of the process reaction curve method.

2. The error for the PID algorithm is calculated as E = SP - CV (not E = CV - SP). The choice of sign is

$$\mathbf{MV(t) = K_C \left[ E(t) + \frac{1}{T_I} \int_0^t E(t')dt' - T_D \frac{dCV(t)}{dt} \right] + I}$$

- ☐ arbitrary ☺
- ☐ to ensure that the value of the error is greater than or equal to zero
- ☐ needed when the set point value is changed.
- ☐ required for negative feedback.

Question 2 encourages students to inquire why the calculation was designed in a specific manner. Students should strive to understand what is a) fundamental, b) an approximation, and c) arbitrary.

3. Errors in empirical models used for tuning occur (see Figure 4)

- ☐ due to the linearized approximation. ☺
- ☐ due to noise in the data used in empirical methods. ☺
- ☐ due to changes in plant operation, e.g. production rate. ☺
- ☐ due to round off errors in calculations.

Question 3 raises the issue of why modelling errors occur. This is an important topic that is often resisted by students who want to believe that all models are very accurate; this belief might result from teaching methods in previous courses. We see that several answers can be correct, and in a few cases, none of the proposed answers is correct. This keeps the students alert.

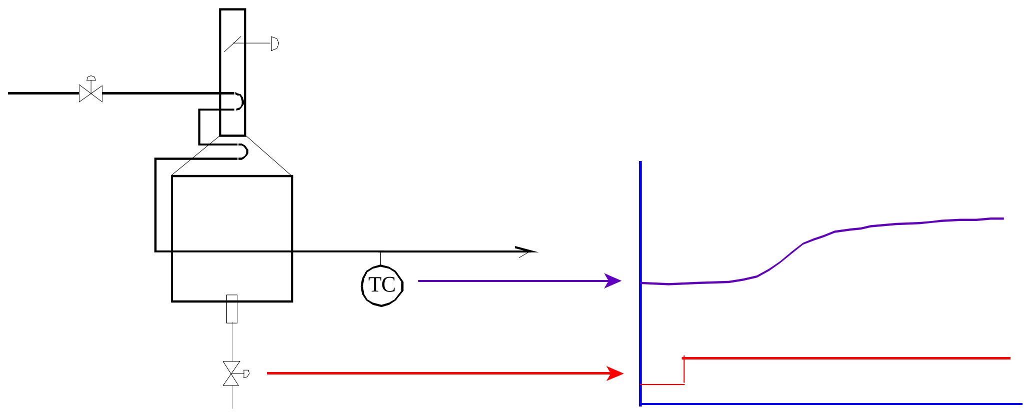



Figure 4. Sample process reaction curve experiment.

**Study Questions:** The next step for students is to apply their understanding to the *Study Questions*. The *Study Questions* require the student to fully understand the textbook contents and then, develop an answer to a new aspect of dynamics and control. To encourage interaction the questions are simpler than the typical end-of-chapter problems. Some of the questions follow up textbook solved problems, because the authors believe that students do not initially strive to understand these valuable resources. The solution provided for the students is complete enough to explain the concept and might include fundamental modelling or results of a dynamic simulation.

Students learn to apply fundamentals to familiar processes and determine useful engineering applications. Some examples of *Study Questions* follow.

4. Diagnose the control performance in Figure 5 and recommend any needed changes to the feedback, PI controller tuning.

☐ The performance is acceptable; no change to the tuning recommended.
☐ Increase the controller gain, $K_{c.}$
☐ Decrease the controller gain, $K_{c.}$
☐ Increase the controller integral time, $T_{I.}$ ☺
☐ Decrease the controller integral time, $T_{I.}$

Practicing engineers must trouble shoot performance on a daily basis. This question provides the student with the opportunity to apply guidelines on patterns of good and poor feedback performance and recommend actions for improvement.

5. This question is an extension to a textbook example on a three-tank mixing process shown in Figure 6. Describe the response of the composition feedback control system to the following disturbances.

☐ An increase of the supply pressure of the pure A fluid
☐ An increase of 10 K degrees in the fluid B temperature
☐ An increase of 30% in the flow of fluid B

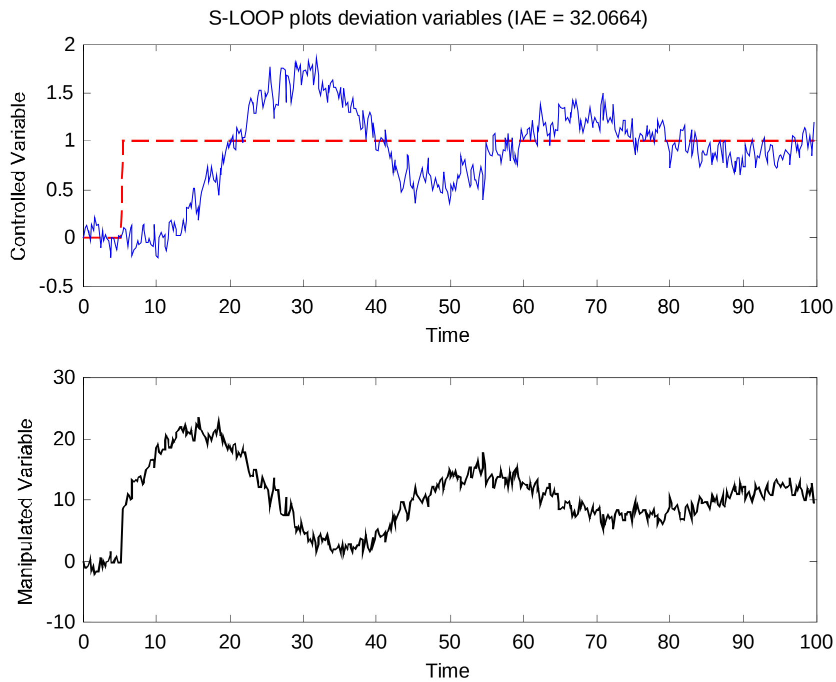



Figure 5. Closed-loop response with proportional-integral controller.

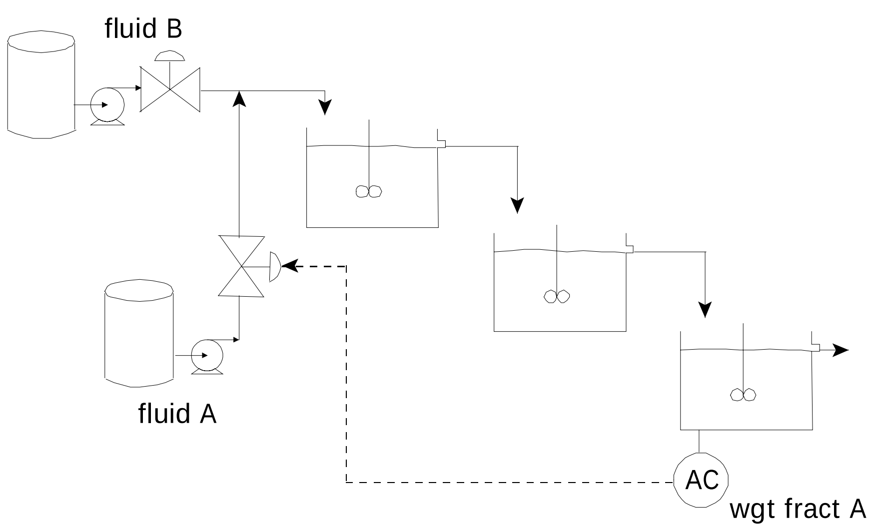



Figure 6. Three-tank mixing process with feedback control.

Question 5 requires students to reconsider a feedback system originally developed to respond to a feed composition disturbance. This question helps students to recognize the power of feedback control that responds to all disturbances affecting the controlled variable. The question also provides an approach for testing understanding that students can apply to many other control designs encountered in the course.

**Thought Questions**: The final category is *Thought Questions,* which provide an opportunity for open-ended problem solving. Again, they emphasize basic principles that link process control with other engineering topics, and they address issues in industrial applications and in everyday life. *Thought Questions* can be used during tutorials, where student groups can share their answers and receive guidance from the instructor. Alternatively, they can be used as self-study assignments to help students develop their library and report writing skills. Examples of a Thought Question follow.

6. Several constitutive models were used in Chapter 3. Discuss how engineers determine the form of each equation and values for the parameters.

- ☐ $-r_A = k_0 e^{-E/RT} C_A$
- ☐ $h = a F_c^b$
- ☐ $F = C_v \sqrt{\Delta \mathbf{P} / \rho}$

Question 6 requires students to recognize that constitutive equations are not uniformly applicable and contain parameter values appropriate for specific conditions. The students can recall the approaches covered in other courses to select the proper model structure and parameter values. The instructor should monitor answers to see if students comment on the likely accuracy of each of these models.

7. Discuss the experiments that you would have to perform to determine dynamic models between the following inputs and outputs. Consider issues like 1) the size of the input changes, 2) the duration of the experiments, and 3) factors (disturbances) that could change during your experiment to lead to poor results.

| **Input** | **Output** |
|---|---|
| Income Tax Rate | Gross Domestic Product |
| Jail Term/Conviction | Rate of Crime in a Country |
| Police Patrols | Deaths due to Impaired Driving |
| Combustion of Fossil Fuels | Average Earth Temperature |
| Average Exercise | Life Span |

Question 7 points out the difficulties faced by modellers who cannot perform designed experiments. We should always respect the challenges and accomplishments in other disciplines.

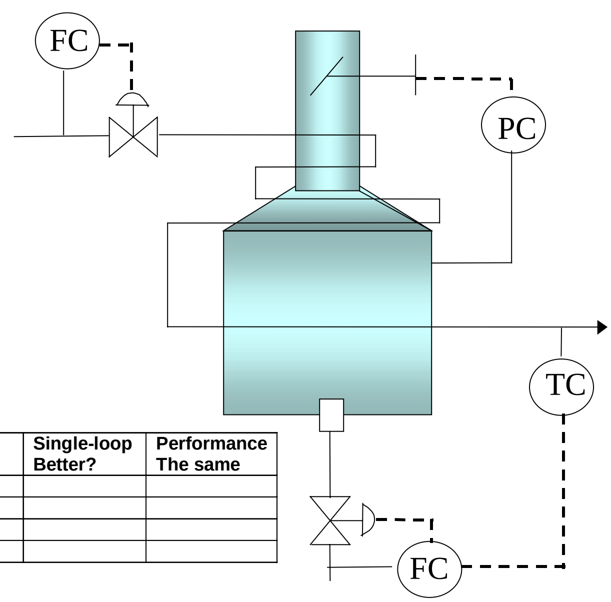
### 5.2 Tutorial Exercises

Tutorial exercises are designed to extend the students' understanding from basic concepts to practical applications. The questions are more complex and require extensive solutions. In some cases, computer software is required to answer the questions. In addition, the solutions contain discussion of the relevance of the problem, i.e., how the problem contributes to a full understanding of the topic. A few examples of questions follow; the questions have been abbreviated and no solutions are given to conserve space in this paper. (Recall that the site is open.)

8. Cascade control can improve performance greatly if designed properly. Consider the design in Figure 7, which shows a cascade design to replace the single-loop temperature to fuel valve control. For each of the disturbances in the table, discuss whether cascade control would be better than/the same as/worse than single-loop control.

9. For the control design in Figure 8, explain whether the design is correct and will function, i.e., the controllers can maintain their measured variables near their set points. If the control design cannot function, suggest a modification that will achieve all or part of the desired function.

These exercises have been selected from years of experience to test the students, yet be within their ability to apply the concepts that they are learning. The questions are challenging and could be frustrating; thus, rapid feedback via complete solutions is essential. Often, modifications of some of these questions are discussed during class tutorials, to reinforce concepts.




| Disturbance | Cascade Better? | Single-loop Better? | Performance The same |
|---|---|---|---|
| 1. fuel pressure | | | |
| 2. fuel density | | | |
| 3. sticky fuel valve | | | |
| 4. feed temperature | | | |

Figure 7. Example of cascade control for a fired heater.



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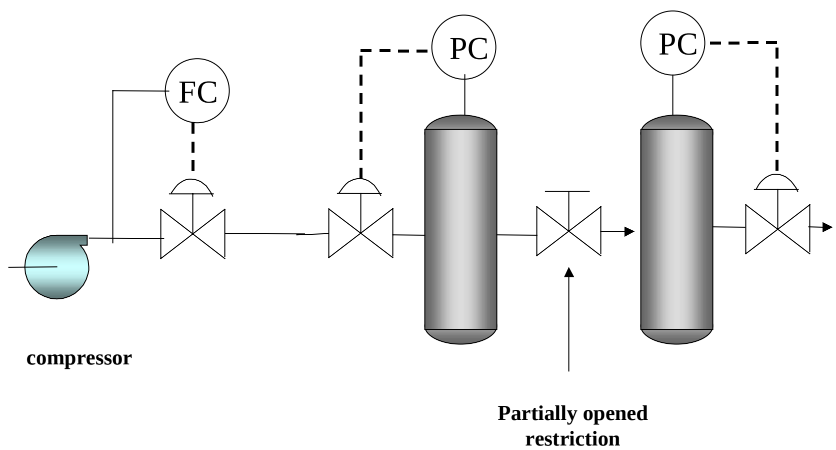


Figure 8. Proposed multiloop design for evaluation. A compressor raises the pressure of a gas that flows through several vessels to a constant exhaust pressure.

## 5.3 Instrumentation Notes

The third component of the site is more conventional; it provides reference materials for instrumentation: sensors and final elements. As noted, this is a sorely ignored topic. However, students are nor well served nor do they respond well to instruction on specific equipment, e.g., orifice plates or ball valves. The key learning goal is the application of criteria for selecting instrumentation; this skill can be applied in essentially any technical career. Therefore, the resources provide an overview of the important terminology and approaches and guide the student to some of the most useful sites on the WWW. In addition, some example problems are given with answers.

Students use this material to answer questions posed by the instructor (and later, by themselves). Typical questions are given below.

10. For the Maleic anhydride plant in Figure 9 (which the students also study in their steady-state flowsheeting course), recommend a flow sensor (F4) and control valve body (v4) for the air flow. Explain your recommendations.

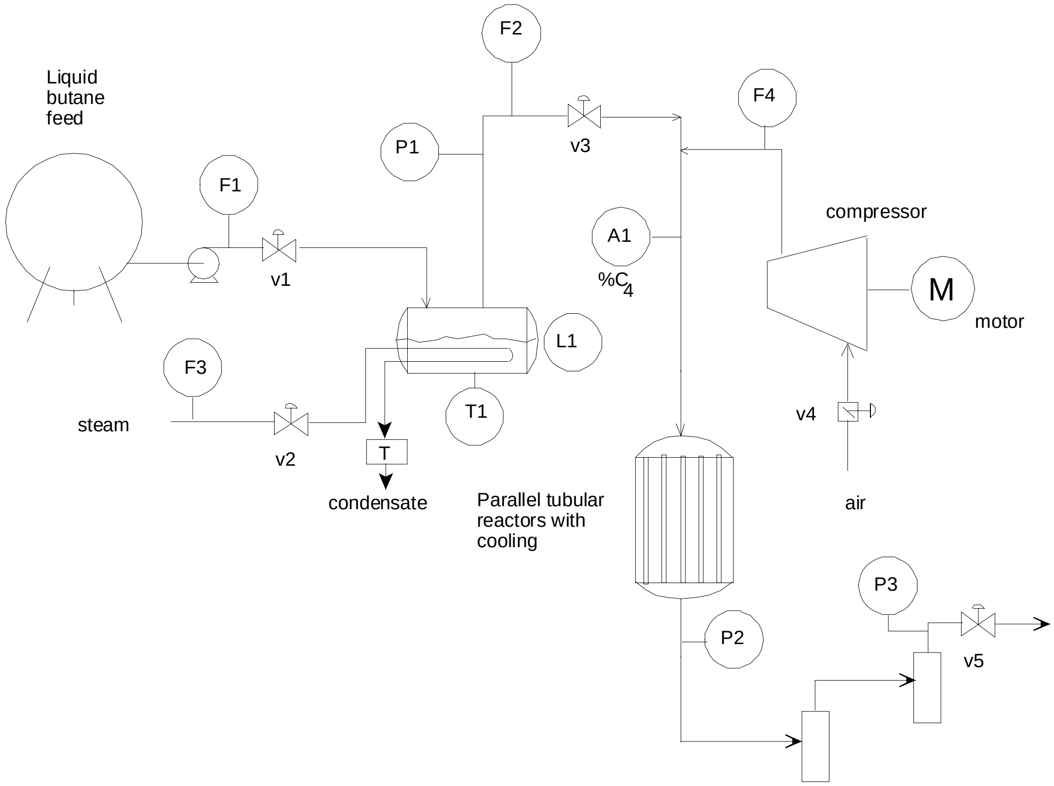


Figure 9. An industrial process for the manufacture of maleic anhydride.

11. We are designing a food manufacturing plant and have to store many products in tanks. Recommend a level sensor for each of the following processes.
a. A granular solid, which might not be evenly distributed throughout the tank.
b. A sticky fluid.
c. Essentially pure water.

Instrumentation questions can posed throughout the course, since instrumentation for monitoring dynamic responses is important, even when the students have not yet learned feedback control.

6. Encouraging use & building learning skills

In the beginning of the course, the instructor will need to emphasize the value of the learning materials and encourage students to engage in self-study. A few exercises should be performed during class to introduce the tool and demonstrate its interactive capabilities. Also, some tutorial time could be allocated to the Interactive Learning Modules, if WEB access is available for students in the tutorial. After limited introduction, students will integrate the WEB site into their study procedures.

Without further instruction, the students will acquire substantial knowledge in process control from the site. That result alone would justify its use. However, we believe that an even greater benefit is possible if this resource is used to build active learning, self-study skills, also referred to as self-directed learning. In self-study, students define their learning goals, investigate the topics, and establish a method for evaluating their learning[9].

A particularly effective manner for reinforcing skills is to have students develop additional ILM and Tutorial questions. The instructor should provide guidance and exercises to teach students how to critically read technical material and formulate key questions. In formulating *Check Your Reading* questions, the students should first clearly identify key fundamental principles and application guidelines with appropriate assumptions. Then, they should formulate questions to reinforce these principles. For example, question 1 above tests 1) knowledge of the process reaction curve equations and 2) understanding when assumptions can (and cannot) be relaxed. Question 2 above points out the lack of fundamental basis for the sign of the calculated error; few students recognize this without some discussion.

In formulating *Study Questions*, students should begin by carefully considering textbook solved examples. First, they should attempt to identify the key learning goals. Then, they should modify the question formulation; for example, what if the flow rate rather than inlet concentration changed? Would this be a likely scenario? Do the same solution methods apply; is the problem substantially easier or more difficult? With this approach, students must evaluate new facets of a physical problem and develop new solutions. This perspective will help free students from the tendency to learn many examples by rote.

Another important aspect of self-study is seeking new applications of knowledge, which can be improved through *Thought Questions*. The questions may address industrial practice or broader issues in applied science and are likely to lie outside the coverage of standard textbooks. The instructor should clearly indicate the key challenge is research skills, so that the students do not become frustrated or claim the instructor is not providing all necessary information. One approach to gain student enthusiasm is to provide open-ended questions to encourage students to follow their interests. One typical question is "*In a two-page typed paper, discuss how process control affects <u>one</u> of the following: plant profit, plant safety, worker satisfaction, product quality, or environmental impact. You must provide at least one specific example and support your conclusions with literature references to published documents*."

The same procedure can be followed for *Tutorial Exercises*. The students should be able to explain why a topic is important to understand and how their question builds a full comprehension of the topic.

Instrumentation questions should be related to a specific process application. The instructor could select an application with which the students are familiar from projects in this or another course.

The instructor can ask student teams to formulate questions for a designated number and set of learning goals; the students should prepare their solutions on separate papers. Then, students can exchange the questions during a tutorial; each team can provide answers and critique the learning value of their classmates' questions. These exercises will assist the students' learning skills while building process control knowledge.

## 7. Student experiences

Educational materials have value only so far as they benefit students; therefore, we need to measure the student's impressions. During initial development, students testing the prototype exclaimed, "Why didn't you let us use this?" (It wasn't available.) The students seemed to like the interactive nature of the learning tool and believe that the presentation and interaction greatly increased the effectiveness of the content.

While the initial concept has withstood the test of time, several features have continued to undergo modification in response to student feedback. One consistent feedback from students was the importance of the touch and feel of the interface. Perhaps, the high quality of Web sites and computer games has raised the stakes for acceptable computer-based educational tools. Students were highly critical when small items did not conform to expectations; for example, dissatisfaction was expressed when every navigation icon did not appeared in the *exactly* the same location on every screen.

When evaluating feedback on specific questions, we were initially puzzled by the students' responses. However, we soon saw the pattern: *students wanted figures with every question*. This is likely a desire to understand the physical context and conceptual structure of the system. Upon reflection, we certainly found this to be a reasonable request whose implementation has greatly improved the quality of the educational materials. Why didn't we do this in the beginning? We have found that developing and drawing these figures can double the development time for a question.

Also, some students wanted to see a link between the Interactive Learning Modules and simulation software. It is likely that some concepts would be reinforced by a simulation case. To maintain the ease of use, the simulation interface should be simple. Thus, we envisage an approach allowing limited user flexibility for a selected exercise; for example, the student could change only the controller gain and integral time for a fixed process, noise, and input disturbance. However, intensive simulation exercises, involving student problem solving and in some cases limited programming, require a more complex interface to accommodate the open-ended nature of the activity. Therefore, extended simulation tools will remain separate from the *Interactive Learning Modules*.

In the spring of 2001, students were asked to complete a voluntary, confidential questionnaire on the WEB site. About 75% of the student completed the forms. The results of three key questions are summarized in the following.

| | |
|---|---|
| • *Did you find the Interactive Learning Modules useful in your studies?* | Over 90% replied "yes". |
| • *Did you find the Tutorial Exercises useful in your studies?* | Over 90% replied "yes". |
| • *Did you find the Instrumentation Notes useful in your studies?* | Over 95% replied yes.<br>(See the following comments.) |

The acceptance is clear from the responses to the first two questions. Recall that the students were not required to use these resources, and a few chose not to. The instrumentation responses look very positive; however, the students were required to use these in answering some assignment questions. Further probing showed that only 20% were interested in self-study; the others used the Instrumentation Notes only as references for *required* assignments. We believe that this is a symptom of the low priority given measurement in the curriculum, and it represents a continuing challenge for this course and site development.

Finally, student responses indicated little interest in a chat room for this course. Perhaps, this response is due to the small class enrollment (about 40 students) and the frequent personal contact among students in several classes per semester.

## 8. Conclusion

The *Process Control Web Site* provides a unique environment for *active* learning possible only via computer implementation. This concept has been exploited to provide guided exercises for process control to build expertise through three components; the Interactive Learning Modules (*Check Your Reading, Study Questions, and Thought Questions*), Tutorials, and Instrumentation Notes. Students can use this self-study resource to complement existing features of the university course. We recommend that the instructor capitalize on this opportunity by including learning exercises in the course to help students build self-study skills. Typically, these exercises will involve formulating, solving, and critiquing new questions. The structure has great potential for linking to other WEB sites and interactive simulations.

## Acknowledgement

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