2006-1686: LEARNING-BY-DOING AND COMMUNICATIONS WITHIN A PROCESS CONTROL CLASS

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Learning-by-doing and Communications within a Process Control Class

Abstract

Providing realistic experiences for engineering students is complicated by a number of factors including a lack of equipment, technician support, and meaningful communication experiences to name a few. To overcome the first two factors computer simulations have been used but these are often lacking in the fullness of details that real systems provide. Meaningful communications are also difficult if there are no consequences tied to the effectiveness of the communication. Over the past four years we have been examining a number of approaches for using remotely located experiments to overcome these difficulties. More recently we have restructured our approach to also emphasize communications skills.

To provide the learning-by-doing experience we used the Green Engineering theme experiments of the on-line laboratory facilities at UTC. To emphasize the communications aspect, WSU students were paired with other WSU students for conducting experiments. By working with their classmates peer pressure is brought to bear to encourage full participation by all students in the activity.

The assignments divided into three parts: a data acquisition step, where the student had to request tests that characterized the system, a data analysis task, using data from the acquisition step, and a performance step, where the student had to instruct another student in order to obtain a specified performance for their system. While student's prefer the easy route most of the students in this year's group learned valuable lessons beyond just process control. It would appear that this is one of those situations where you may not like the approach but you realize that in the end it is good for you.

Introduction

Providing hands-on, or learn-by-doing, experiences for engineering students is often complicated by either a lack of equipment, technician support, or both. Yet most topics in chemical engineering are best learned via a learn-by-doing approach. Computer simulations have been used in lieu of a truly hands-on experience but these are often lacking in the fullness of details that real systems provide. With the advent of high-speed Internet communications, an alternative approach to providing hands-on experiences has become possible – remote operation of real equipment. Both this group as well as faculty at the Massachusetts Institute of Technology and the University of Cambridge have demonstrated this[1,2]. Such remote operation experiences are fully learn-by-doing with nearly all the positive and negative aspects of true hands-on laboratory work. Such an approach can, however, be frustrating for students at the remote site if the equipment malfunctions.

The process control class at Washington State University is taught in the first semester of the senior year. The class is typical of many ChE-based control classes. The course objectives state that the students should be able to:

1) analyze the dynamics of process operations
2) understand the dynamic response of various operations
3) understand PID controllers for process operations based on both theoretical and empirical process characterization

The outcomes arising from the objectives outlined above are intended to partially satisfy ABET outcomes a, c, e, and k as well as the AIChE outcomes of demonstrating a working knowledge of material and energy balances applied to chemical processes, process dynamics and control, and appropriate modern experimental and computational techniques.

In the past this course was taught in a traditional manner – covering the mathematical bases of process dynamics (unsteady-state balances, Laplace transforms, etc.) first before going on to cover control and tuning. Starting in the Fall Semester of 2002 the coverage of topics was changed with students analyzing process dynamics and tuning first, followed by coverage of the mathematical aspects and then more recent developments in control schemes. The initial homework assignments thus required that the students collect data from a process. With this data the students then can tune various types of controllers to get the desired response from the system.

As a result of our desires to insure a hands-on aspect in this class a collaborative effort between the University of Tennessee at Chattanooga (UTC) and Washington State University (WSU) has developed. In the Fall Semester of 2002 students in the Process Control class at Washington State University received homework assignments requiring the use of the Resource Center for Engineering Laboratories on the Web (http://chem.engr.utc.edu) at the University of Tennessee at Chattanooga (UTC). Since only one student can be using this site at a time there were scheduling conflicts near the due date for any assignment when multiple students tried to access the website simultaneously. As a result, in the Fall Semester of 2003 the class was conducted as in the first year but with a sign-up procedure in place so that student knew when she/he would be able to access the site[3]. While this solved the scheduling difficulty there remained the problem of equipment "malfunctions", times when the equipment did not behave properly.

Discussions between the two co-authors developed a resolution to this problem as well as a way of bringing more real life variations into the assignments[4]. In the Fall Semester of 2004 students at both UTC and WSU were paired. These assignments were divided into two parts. The first was a process characterization experiment where the WSU student was to request a step change trial to characterize the dynamics of the process being studied. The UTC student would run the experiment as requested and return the raw data to the WSU student. The WSU student would develop a model for the process that would be used to obtain a desired response (quarter decay ratio, 5% overshoot, etc.) to a step change input when a PI controller was used to control the process. The WSU student would direct the UTC student to set the controller tuning parameters to the desired levels then conduct the step test. If the desired performance criteria was not met the WSU student could request further trials, but only up to a maximum of four. Thus, in addition to the process control problem, the student pairs had to struggle with the problems of communication and time management on both sides.

While the process characterization portion (first assignment) went very smoothly, the performance testing portion of the experiments (second assignment) began to break down. In large part this may have been due to the timing of this latter aspect of the process as the due date was during the next to the last week of the semester at WSU, which corresponded to the last week of classes at UTC. The result was that a considerable number of students at WSU did not make their requests in a timely fashion and, as a result, did not get a response from the partner at UTC.

Current Procedure – Process Characterization

To overcome these difficulties a new approach was tried during the Fall Semester of 2005. The idea of pairing students to conduct experiments still seemed like a good way of combining typical process control problems with realistic communications problems. In addition, the use of real equipment, rather than simulations, was also seen as a positive. What was needed was a way of getting greater buy-in by both students in the pair so that everyone felt a need to complete all parts of the assignment. This was accomplished by forming pairs between WSU students only. Thus peer pressure, the knowledge that you were working with a classmate, was brought to bear on all of the students in the class.

After covering a variety of tuning procedures in class, and their consequences, the students at WSU were given an assignment requiring that they obtain process data from real equipment in order to build a dynamic model. An example of the assignment sheet is attached as Figure 1. The real equipment they were to test, however, was not located locally, but was located at the University of Tennessee at Chattanooga campus. Access to the experiments was via the Internet via the site www.rowan.edu/greenengineering. Three different experiments from the System Dynamics and Control section were used – the Paint Spray Booth Pressure System, the Filter Wash System and the Aerator Mixer System. The process description for the Paint Spray Booth Pressure System is shown as Figure 2. Similar descriptions, downloaded from the Green Engineering website for the Filter Wash System and the Aerator Mixer system, were also supplied. The students were not informed of the existence or location of the website at this time. This information was withheld in order to force the students to think about what they were going to request rather than allowing them to try their task first, then write a request that they knew was going to work.

The class at WSU was divided into thirds with each third being assigned to perform the process characterization test for one of the three possible processes described above. Each group would ultimately end up conducting some sort of activity with each of the three modules, as shown in the table below.

Table 1: Distribution of Activities

Group	Step Test Request	Step Test Performed	Performance Test Performed
A	Paint Spray Booth	Aerator Mixer	Filter Wash
B	Filter Wash	Paint Spray Booth	Aerator Mixer
C	Aerator Mixer	Filter Wash	Paint Spray Booth

An example of one of the memos generated by the students is shown in Figure 3. Thus a student in Group A would write a request for a step test appropriate for the Paint Spray Booth module. This memo would be sent to a student in Group B, who would actually perform the step test. No identifiers were allowed on the memo so no student knew who had written the memo. When the request memos were received by the instructor (RZ) they were all placed into a standard format and given to the students who were going to actually perform the step test. An example of an assignment given to a student is given in Figure 4. Thus all students were asked to collect data on systems other than those for which they wanted data.

The data which had been collected by the students was returned to R. Zollars. These then were returned (anonymously) to the student who had originally made the request. The students then were asked to develop an appropriate process model from the data they had obtained. An example of the assignment containing the step test data is attached as Figure 5. For those students who felt that the data they had received in response to their initial request was unusable, a second process characterization request was allowed. Out of 20 students in the class only four such requests were made. The students were also asked to comment on whether the results they received were what they had anticipated and how they might improve their instructions in the future. This completed the process characterization segment of the assignments.

Procedure – Performance Criteria

As before, the process characterization was followed by an assignment in which specific performance responses were requested for a process. An example of such an assignment is also attached as Figure 6. The sequencing of the assignments thus proceeded as follows. A student, say from Group A, would write a memo describing a characterization test they wished to have performed. This memo was passed to a student in Group B who actually performed the test. The data was returned to the original student who had to fit an appropriate model to the data. This model was then passed on to a student in Group C who was instructed to develop a set of tuning parameters to obtain a specified performance from the system. As can be seen from this memo, the data given to R. Zollars by the student doing the model identification was given to the student conducting the performance criteria testing as received. In this case the results were given with no units, thus no units were given to the student doing the performance testing.

As with the characterization portion of these assignments the students were limited in the number of trials they could conduct. This limitation was imposed to avoid having students obtain the desired result by brute force (since this typically would not be allowed in a real world setting). This limitation required that the students conducting the Performance Test aspect think about what settings they were going to use, based either upon heuristics or results from prior tests. To make better use of their limited number of trials on the remote site, most students entered the model they had received into either Control Station® or into Matlab. Using either, or both, of these software packages the students could simulate the results they would expect from actually conducting the experiment on the UTC site. When they felt that they had an appropriate set of tuning parameters for the task required they then would actually go to the UTC and conduct the experiment on the real equipment.

At the completion of all three phases the students were given a survey to determine whether the goals of performing experiments on real equipment and adequately communicating between various, unknown students had been accomplished.

Results of the Characterization Experiments

The results of the characterization phase were, for the most part, very good. As mentioned earlier students were given a chance for a second experiment if they felt that the original data they received was not sufficient for them to complete the remainder of the assignment. Only four out of twenty students elected to exercise this option. The results of the characterization phase were largely uniform for each of the three modules tested. There were some notable exceptions. In one case the test data showed no discernable step change. The student used the Design Tools option in Control Station to fit the data to a first order plus deadtime model. While they got a result the parameter values were highly suspect. The other most common error arose from students just using the Design Tools option without looking at the results. As shown in Figure 7 the data received from the UTC site contained both a start-up phase as well as the step change. If the initial transient was left in the data Control Station tried to fit the entire data set as if it arose from a single step change, as shown in the figure. While this is obvious if one inspects the model predictions with the actual data, a number of students just used the results from the Control Station results without checking to see whether they actually agreed with their data.

Results from the Performance Criteria Experiments

These results are obviously highly dependent on the accuracy of the model supplied to one student by a student who had conducted the data analysis/model identification portion of the assignment. In six of twenty cases the students were easily able to use the data obtained by other students to meet the performance criteria given them in the assignment. In five other cases the student was able to modify the model partially to meet the performance criteria. In five other cases, however, the model was so far in error that the students were unable to meet the performance criteria within the limitations set forth in the assignment. In this case the student needed to realize this situation, then either use the results of a prior test or use a second trial, to appropriately characterize the process before continuing with the performance testing. This would not detract from their grade on this assignment so long as they clearly indicated why they felt the data they had received was inadequate in the memo turned in as part of the final assignment.

Student Responses

Unlike our previous experience, where communication was required between students at two different sites (students who had never met each other except over the Internet) the students in this class had a strong buy-in in all aspects of these experiments since they knew that the other student involved was one of their classmates. The results were that all twenty of the students completed all aspects of all of the assignments. This can be compared to approximately a 50% completion record in the prior year. The anonymity of the students supplying the memos was guarded at all levels and there was no indication that students were able to figure out which of their classmates were responsible for the various memos.

The students were asked to respond to seven different items on a 1 – 5 scale (1 = strongly disagree, 5 = strongly agree). This was followed by seven questions requiring some type of comment. The results from the numerical responses are given in the table below.

Table 2. Survey Results

Item	Survey Statement	Response Avg ± SD
1	Using Control Station was easier than using the University of Tennessee (Chattanooga) site	4.4 ± 0.7
2	Access to the UTC site was readily available	4.2 ± 1.1
3	The UTC site provided a more real life experience than did Control Station	3.2 ± 1.0
4	Being able to test my tuning strategies on real equipment (UTC) helped me learn practical applications of control systems	2.9 ± 1.0
5	Using the Design Tools in Control Station or Matlab for characterizing all processes (whether the data came from Control Station of the UTC site) was not a difficulty	3.8 ± 0.9
6	I feel that I learned the material better using Control Station rather than the UTC site.	4.5 ± 0.6
7	I would prefer using the UTC site rather than Control Station on assignments in the future	1.8 ± 0.8

It is clear from these responses that some of the prior difficulties had been solved. For example, question #2 clearly shows that access to the UTC experiments was not a problem. Using either Control Station or Matlab (question #5) did not present a difficulty for the students. The class split evenly as to whether using real equipment was seen as helping to learn the material. What was also very evident is the strong preference for using Control Station over using the UTC on-line experiments. It was in the written comments that a clearer view of the outcomes arises, as will be discussed in the following section.

Discussion

The intent of this experiment was twofold – 1) to continue to have WSU students exposed to real world data in the process control class, and 2) to reinforce communication skills by requiring students to work with another person in directing, collecting, and communicating data. While the raw data has been summarized above, a closer analysis of the written comments reveals other results.

The numerical results from this group of students clearly shows a preference for using Control Station, a computer simulation, rather than using real equipment through a remote link. An examination of question #5 in the written comments reveals important outcomes. The verbatim comments are given below:

5) *What was the most important thing you learned in conducting this exercise?*

- *Be specific and provide a lot of details. I also learned you should know a system before you start to play.*
- *It was necessary to double and triple check instructions before giving them to another person. Sometimes there is nothing to do but request another test.*
- *That real processes contain a lot of noise and that when data is retrieved by others it is important to have well written tasks to ensure good results.*
- *Pay extreme detail to what you input because there is no way to change anything after pushing run.*
- *Lots of noise.*
- *Real data contains a lot of noise.*
- *You can get any type of data in "real life" and have to deal with it.*
- *Need to know the site first before asking for any data because you don't know how the system works, i.e., the times and parameter, how they are inputted into the system.*
- *The use of Matlab to help tuning. Also, having clear exact instructions on what need to be done is important.*
- *Don't trust data that you didn't conduct by yourself.*
- *Know your system!*
- *That smoothing the data you received from this site was absolutely necessary to see any trend whatsoever.*
- *Patience.*
- *Trust no one.*
- *All three people along the way must not error or it really screws the tuning person.*

It is clear that while the students may prefer using a computer simulation, with its limited range of results, they did learn valuable lessons by using real equipment. A common comment is the need to know your system better before asking for experiments. This is a result of the structure of the assignments, where access to the UTC site, and thus knowledge of the system, was limited during the initial phase of these assignments.

Some description was given but more appears to be necessary to make the students feel more comfortable in specifying conditions for experiments.

Another important insight was the need to be specific in giving instructions. Most students recognized that their original set of directions given for the characterization experiment could have been improved to reduce the differences between what they requested and what they received.

Perhaps the most important insight is that real data contains varying amounts of noise and that you have to deal with it. Of the twenty data sets of characterization data returned to the original requester, varying amounts of noise were present. While most students realized it was there, only two or three actually used some type of smoothing to get reasonable model estimates.

Conclusions

We have tried a number of variations on the theme of exposing students to the complexities of using real equipment to design and operate simple control systems. We have also introduced the need for students to be able to clearly communicate directions and results. By doing this between people within the same class we have overcome the difficulty of getting buy-in by the students. When they realize that it is a classmate who is depending on them they at least put in some effort in completing an assignment. It is also evident that the students would prefer the easiest route. Real data, with its attendant greater uncertainty, is something they would prefer to avoid if possible. While their numerical assessment was neutral on whether they actually learned more about tuning using real systems, their written comments revealed that they had actually learned many valuable lessons about what is needed to adequately instruct another person as well as what to expect from real systems and data.

Bibliography

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[3] J. Henry, R. Zollars, ASEE Annual Conference and Exposition, Salt Lake City, UT, 2004.
[4] J. Henry, R. Zollars, ASEE Annual Conference and Exposition, Portland, OR, 2005.

ChE 441 | **Washington State University**
Process Control | **School of Chemical Engineering and Bioengineering**
Fall, 2005 | **Richard L. Zollars**

Homework Assignment #14
Due: October 21, 2005

You have just been assigned to the process described on the attached pages. Prior to optimizing the controller for this process you first need to obtain information on the process dynamics. Since this process is in constant use you have only a limited ability to perform experiments. Further, only an operator is allowed to make changes to the process. Therefore, you may only request one trail which will be performed by the operator who will then return the data to you. From prior experiences you know that under normal operations the manipulated variable for your process will have a value of 30% and that the system reaches 2/3 of its ultimate change in less than 1.5 sec.

By October 21 write a memo precisely describing the experiment you want performed. The operator receiving your instructions will follow them exactly as written so make sure you are specific in writing your instructions. You will need to specify the level of the manipulated variable you want before and after the step change you will be making. In addition you will need to specify how long after starting the experiment you want the step change to occur and how long after the step change takes place you want to continue collecting data. When submitting this assignment, turn in both a hard copy and an electronic version. Submit the electronic version to rzollars@che.wsu.edu.

Figure 1: Initial Assignment Requesting Characterization Testing

Spray Paint Booth Pressure System

By Jim Henry, Ph.D, P.E.
University of Tennessee at Chattanooga
2004

Our engine assembly plant in Dunlap, TN, has 3 spray-paint booths to paint the engine housings before they are sent to the production line. The 3 rooms are pressurized and the exhaust of each one goes to a filter unit that cleans the air before being released. This air cleaning is required by US-EPA and our state and local Air Pollution Control Agency.

The pressure is provided by a blower that blows air into the booths. The motor driving the blower is a variable-speed blower. The speed of the blower is under feedback control to maintain the desired booth pressure. A diagram of the blower, booth and controls system is shown below.

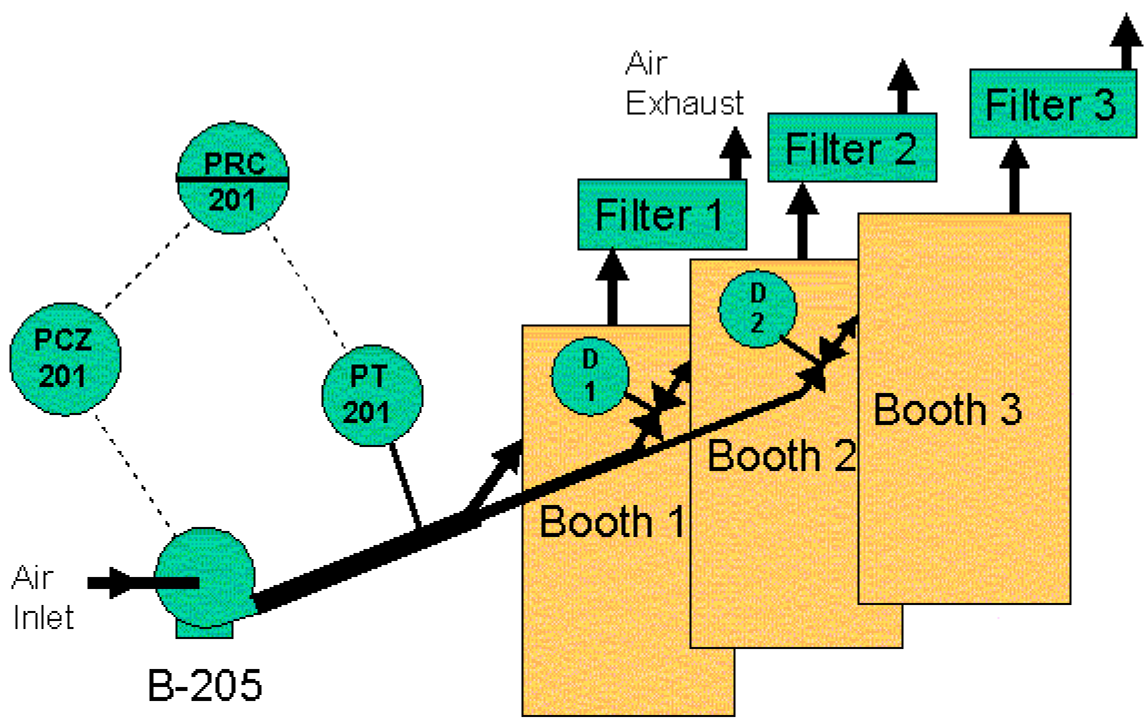

Figure 1. Schematic diagram of the Dunlap Plant Spray-Paint Booths

Figure 2: Example of Process Description from UTC Site

Operational Situation:

The booths are not all used all the time. "D-1" and "D-2" are solenoid-operated valves that cut off the pressurizing air to Booth 2 and Booth 3 when they are not being used. Your job is to determine the relationship between the pressure in the rooms and the speed of the blower motor.

The blower-booth system has an "input function" that is the power sent to the blower-motor; it varies from 0-100% of the rated power to the blower-motor. The blower-booth system has an "output function" that is the pressure in the booth. It is measured in units of cm of water (cm-H2O). The input function is called ***m(t)***, it is usually a function of time. The output function is called ***c(t)***, it also is usually a function of time. The names of the functions come from the fact that later they are called the Manipulated variable and the Controlled variable. A diagram that shows the input-output relation is in Figure 2.

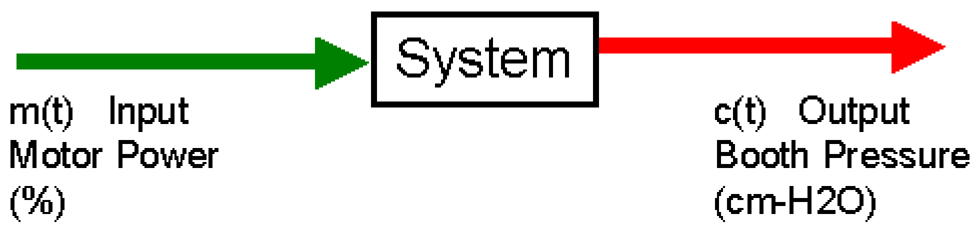

Figure 2. Block diagram of paint Booth System

Figure 2: Example of Process Description from UTC Site

MEMORANDOM

TO: Operator
FROM: Process Engineer
DATE: 10-20-05
SUBJECT: Filter Wash Flow System Controller Experiment

Engineering is interested in determining the proper parameters needed to control the wash water inlet pump (P-305). The operator is requested to carry out the following steps and report data obtained to the engineering department. Before running the experiment, make sure the valves to filter washing stations #2 and #3 are in the off position, and stay off for the entire length of the experiment (i.e., valves MV302 and MV303 closed for 60 seconds, on for 0 seconds). The steps are as follows:

1. Change the baseline input data to 50%. i.e., set the wash water inlet variable speed pump at 50% of its maximum speed. Allow 20 seconds for the flowrate output to come to a steady value before performing step 2. Record the input value % change, and the output flow rate change, from 0 to 20 seconds.
2. Perform a step change of 20%, i.e., the variable speed pump will increase from 50% to 70%. Allow 40 seconds for the flowrate output to come to a steady value. Record the input value% change, and the output flow rate change, from 20 to 60 seconds.

Please send all recorded data to engineering. You will receive a $100,000 raise for duties performed

Figure 3: Student Response to First Assignment

Cougar Controls, Inc.

TO:

FROM: Shift Engineer

SUBJECT: Request for Test (Assignment # 17)

We have received a request to run an operations test on the Aerator Mixer Speed Control system. The specifics of the test are given below. To run this test go to the website www.rowan.edu/greenengineering. Log on using the username *guest* and the password *guest*. Click on the selection "Courses and Modules" listed to the left of the website. Now click on the **+** sign after the heading System Dynamics and Control. This section will be expanded. Find the heading *Filter Wash System - Step Response -- Experiments & Analysis* and click on this heading to conduct your experiment. Remember that your budget and time restrict you to only conducting a single experiment. Follow the directions below to the best of your abilities given this restriction. Two output files will be created, a .txt file and a .xls file. Save both of these a send them to me (at rzollars@che.wsu.edu) by 8:00 AM, October 28, 2005. Also by that date send me a memo answering the following questions:

1) Were the directions you received clear? What was the biggest uncertainty about the directions that you had?
2) Was there something in the directions you received that you were unable to accomplish? What was this?

DIRECTIONS:

Engineering is interested in determining the proper parameters needed to control the wash water inlet pump (P-305). The operator is requested to carry out the following steps and report data obtained to the engineering department. Before running the experiment, make sure the valves to filter washing stations #2 and #3 are in the off position, and stay off for the entire length of the experiment (i.e., valves MV302 and MV303 closed for 60 seconds, on for 0 seconds). The steps are as follows:

1. Change the baseline input data to 50%. i.e., set the wash water inlet variable speed pump at 50% of its maximum speed. Allow 20 seconds for the flowrate output to come to a steady value before performing step 2. Record the input value % change, and the output flow rate change, from 0 to 20 seconds.
2. Perform a step change of 20%, i.e., the variable speed pump will increase from 50% to 70%. Allow 40 seconds for the flowrate output to come to a steady value. Record the input value% change, and the output flow rate change, from 20 to 60 seconds.

Please send all recorded data to engineering.

Figure 4: Example Assignment Requesting Actual Performance of Process Characterization

ChE 441 **Washington State University**
Process Control **School of Chemical Engineering and Bioengineering**
Fall, 2005 **Richard L. Zollars**

Homework Assignment #19
Due: November 7, 2005

You will be sent, via e-mail, files containing the results of the step test you requested on October 21. Your next task is to obtain the best model that you can to fit this data. You may select any model you wish but you do need to give reasons for selecting the model you have chosen.

If you feel that the data supplied to you is not sufficient to adequately provide the requested data please indicate this as there may be some limited opportunity for a second step test. If you would like to request a second step test you will also need to give a justification and instructions for this second test.

On November 7, 2005 please submit a memo containing your recommended model for the process you were asked to test. Also in this memo answer the following questions:

1) Did the person running this test for you conduct the test as you requested? If not, what differences were there?
2) Could the differences be a result of ambiguity in your original instructions? How would you rewrite your instructions to avoid this?

Figure 5: Memo Containing Data from Process Characterization Test

Cougar Controls, Inc.

TO:

FROM: Shift Engineer

SUBJECT: Request for Test (Assignment # 23)

One of the other engineers in our group has conducted a step test on the Filter Wash System. They have determined that this system can be represented by a First Order Plus Deadtime model with a gain of 0.5026, a time constant of 1.03, and a deadtime of 0.256. You need to determine the proper parameters for a PI control system that will yield a 5% overshoot when the set point for this system is changed from 5 lb/min to 4 lb/min. The valves for the two other wash stations should be closed. Because of limited resources you will only be allowed three trials on the actual equipment to obtain the proper parameters. Your recommendations, along with supporting data verifying that the system will behave as required is due in my office by December 9, 2005.

Figure 6: Assignment Requesting Performance Test

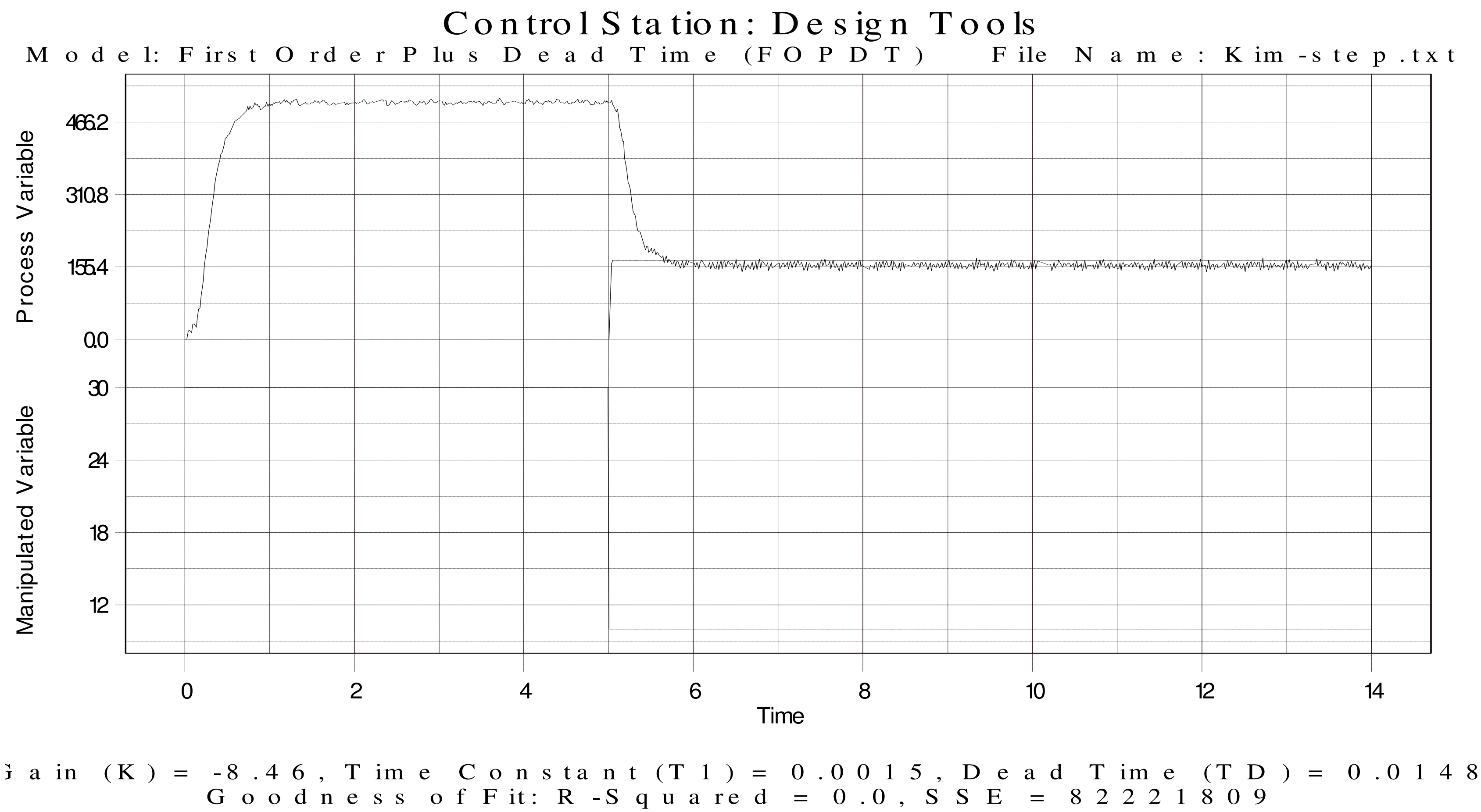

Figure 7: Example Output from Control Station where Initial Transients Have Not Been Removed