Bringing Active Learning into the Traditional Classroom: Teaching Process Control The Right Way

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Abstract

Since joining the faculty of Chemical Engineering at the University of Colorado in 1975, I have taught the undergraduate course in process control 20 times. The course has always had a laboratory component, and, since 1994, this has been a full-featured 15-session laboratory. The classroom portion of the course was taught in a traditional lecture format until the Spring 1996 semester. In the past, the course has been well received by students and, generally, has been complimented by alumni, faculty peers, and practitioners. Still, the persistent difficulty experienced by students over the years in attempting to grasp the more challenging concepts of process control led me to try a different mode of instruction in 1996.

In the Spring semester of 1996, I converted the classroom component of the course to an active-learning format. This was facilitated by being able to teach the course in the Bechtel Active Learning Center of the Integrated Teaching & Learning Laboratory (ITLL), a new instructional facility in the College of Engineering and Applied Science at the University of Colorado. In lieu of traditional lecture, I wrote over 40 active-learning workshops. Students are organized in groups at small conference tables. My instruction primarily consists of wandering the room, answering questions posed by the groups, and coaching. Only occasionally do I speak to the class as a whole. Conversion of the course has provided two important benefits: students were extremely positive about the learning environment and students grasped important, difficult concepts better than they had in previous years in the traditional lecture format. From my perspective, it is also important to note that, after all, it is possible to teach an old dog new tricks.

Introduction

One of the first AIChE National Meetings I attended was the annual meeting in Los Angeles in 1975. There was a session at that meeting that provided an overview and evaluation of the teaching of process control. This was particularly timely for me as I was about to teach process control for the first time in the Spring 1976 semester. The strongest message from the session was that students and control practitioners believed that the courses being taught, texts being used, etc., were far too abstract and disconnected from the reality of chemical process control. My prior experience had included several years at DuPont doing instrumentation and control work on numerous plant sites. One of the real attractions control always had for me was that it allowed for the bridge from the abstract to the concrete. Perhaps, the problem was rooted in that those teaching control *had never done control*.

Consequent to my experience at that AIChE meeting, I incorporated three laboratory exercises (instrument calibration, dynamic testing, controller tuning) into the control course I taught at the University of Colorado[1], and I tended to choose text materials that had at least some practical content. The course continued in this form through 1993. At that time, and due to other curriculum changes, it was decided to add a credit hour to the course and develop a full laboratory component, 15 different experiments running throughout the semester.

In the Fall 1996 semester, I took over instruction of a Junior-level course, Applied Data Analysis, that had a poor prior record of student evaluations. The course had been taught in two 75-minute, traditional lectures per week at 8 a.m. on Tuesdays and Thursdays. Lengthy, early morning lectures on statistics is, perhaps, a prescription for failure. I converted the course over to an active-learning format[2]. In doing so, I replaced the lectures with 28 workshops where students worked on concepts and methods in groups. Most of my teaching was in a coaching mode, wandering among the groups. I did retain a very limited amount of lecture time at the beginning of class, to launch the workshop, and at the end of class, to bring closure. The response of students to this active-learning approach was overwhelming and positive. This tempted me to convert the classroom component of my already-successful control course to an active-learning format. During the Spring 1997 semester, I wrote 41 workshops on-the-fly for use in the course. In the Spring 1998 semester, I am teaching process control for the 21st time and using the active-learning approach for the 2nd year.

Course Objectives and Outline

All required courses in Chemical Engineering at the University of Colorado have published learning objectives. These have been developed and approved by the faculty and are distributed to students at the beginning of each course. The course being described here is Instrumentation and Process Control (CHEN 4570, 4 credits, Spring Senior), and its objectives are:

1. Chemical Process Instrumentation
   - knowledge of industrial technology for measurement of pressure, flow, and temperature
   - knowledge of instrumentation signal types and transmission methods
   - appreciation for considerations of accuracy, precision and cost of process instrumentation

2. Process Control Concepts
   - understanding of typical process control structures: feedback and feedforward
   - ability to develop fundamental and empirical mathematical models for process dynamics
   - thorough understanding of transfer function description of process dynamics & stability
   - understanding of dynamics & stability of closed-loop systems

3. Design of Process Control Systems
   - knowledge of typical industrial feedback controllers (P-only, PI & PID) and their application
   - ability to design conventional feedback & feedforward control systems, including parameter specification
   - understanding of the frequency response analysis of control systems & stability
   - understanding of at least two more advanced topics in process control from the list: cascade control, deadtime compensation, internal model control, adaptive control, multivariable control

4. Installation & Adjustment of Process Control Systems
   - skill in calibrating process instruments
   - skill in fabrication of electronic circuits common to process instrumentation
   - ability to carry out dynamic tests of processes and determine empirical models from the results
   - ability to synthesize, implement, and adjust computer-based controllers on laboratory-scale processes

The reader who teaches process control will notice several features right away:
- the inclusion of practical material on measurement and control instrumentation,
- the retention of the topic of frequency response (many courses are now leaving this out),
- the limited exposure to advanced topics.

The topical outline of the course provides its backbone:

Introduction, Modeling, and Math Background
Process Dynamics
Controllers and Instrumentation
Feedback Control System Design
Frequency Response
Feedforward, Cascade & Advanced Control

Laboratory Component

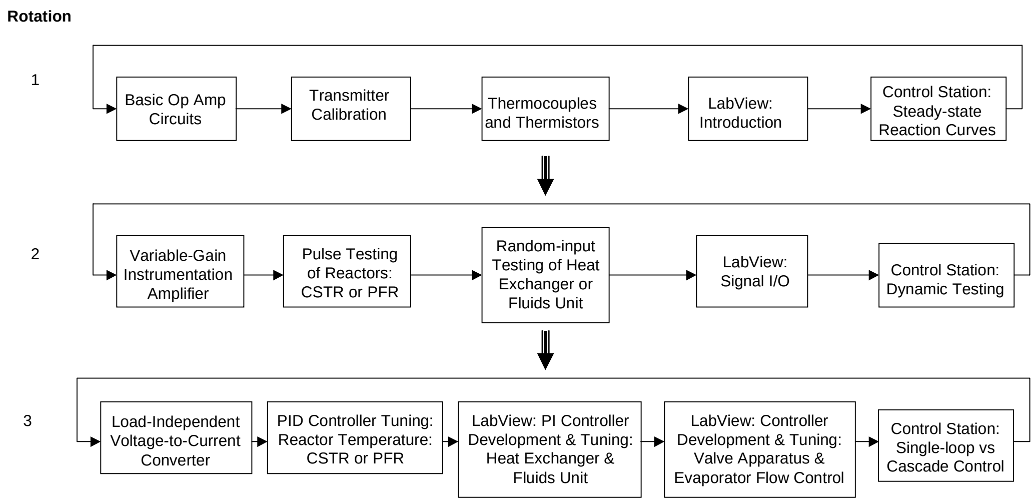
Building in the laboratory component of the control course was a measurable task. The first challenge was an organizational one: *How do 60 students complete 15 different lab projects?* This was accomplished in the following way:
- two lab sections meeting once per week for 3 hours, 30 students each
- 10 groups of 3 students per lab section
- 5 duplicate experiments, allowing 10 experimental sites per lab session
- 3 5-week rotations, with student groups doing a "round robin" of projects within each

The organization of 3 rotations allowed for a progression of themes, the same ones from the original course design:
- basic instrumentation
- dynamic testing
- controller implementation

There are also several content threadlines that interconnect the rotations:
- LabView real-time programming
- electronic circuits
- Control Station simulations
- dynamics and control of unit operations

and it is contemplated to add a threadline in programmable logic control (PLC) of batch processes.

A summary of the lab organization is presented in the figure below:



Active-Learning Component

During my somewhat lengthy career of teaching process control, I have worked diligently on my performance as a lecturer, keeping well in mind the well-publicized necessary conditions to excellent teaching:

- knowledge of subject
- organization
- communication
- rapport
- fairness

Much of this work focused on my performance. After enough time, I felt I had squeezed as much performance out of myself, and yet I was dissatisfied in two aspects of the students' experience in the course:

- extent of learning of the more challenging concepts in the course
- relative lack of enthusiasm of the students toward a topic that is my life's work

It is not without some trepidation and forethought that I reached the commitment to develop 41 active-learning workshops for the Spring 1997 offering of the course. I had just completed doing that for another course (Applied Data Analysis) and certainly realized the extra work involved. But, evidently, the motivation was there.

There are two significant differences in the workshop suite for Instrumentation and Process Control from the suite for Applied Data Analysis. First, in the Applied Data Analysis course, the workshops were the students' only hands-on experience; whereas, in the Control course the students have a rich and varied set of hands-on experiences in the laboratory component.

Consequently, the Control workshops are more derivational or conceptual in nature, while the Data Analysis workshops generally have a tactile experimental feature.

Second, in the Data Analysis course, I followed a fairly rigid *modus operandi*: a 10-minute mini-lecture, a 10-minute example problem with Q&A, followed by a 45-minute workshop and a 10-minute windup. This was modeled after the efforts of Jones and Brickner at Purdue[3]. In the Control course, I am constrained to a 50-minute period, and I chose to vary the format from class meeting to class meeting. The differing formats include:

- a 5-to-10-minute mini-lecture followed by a group workshop
- a group workshop that consumes the entire class period
- a series of software demonstrations that students document on a set of workshop sheets
- a quick exit of the room to an adjacent computer lab where students complete a computer-based workshop using one of the course's software tools
- an interactive lecture punctuated with short group activities

The motivation for varying the format of the workshops was two-fold:

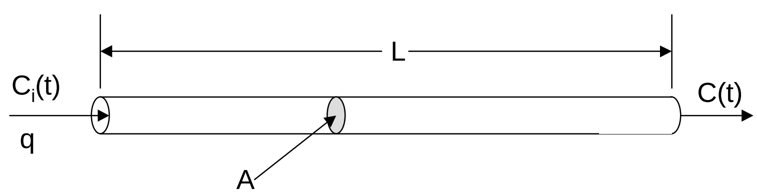
- to prevent students from falling into a rut with a single format – keep them on their toes
- to see whether one format worked better than another

Although I do not include complete examples of the workshops here, I present an excerpt in the figure below. All workshops are available to the interested reader.

Class Exercise #14

Time Delays

The typical cause of time delay in chemical process systems is transport lag. Consider fluid flowing through a pipeline under plug-flow conditions. See the figure below.



A time-domain equation that describes the concentration at the exit in terms of the concentration at the inlet is

$$C(t) = C_i(t-\theta)$$

where θ : fluid residence time in the pipe

What formula would you use to calculate θ ? ________________________

Apply the Laplace transform to the time-domain equation to develop a transfer function for the pipeline.

Now, consider a simple mixing process with a recycle stream.

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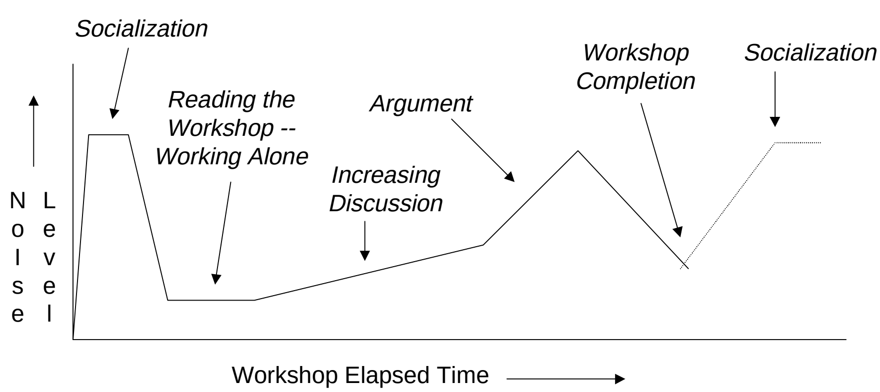
There are some that will say that I am shirking my instructional responsibility because I am not at the front of the class “teaching.” In ways, “teaching by walking around” is more difficult and more tiring for the instructor. Tuning in on many student groups and coaching them requires quick thinking and a very thorough knowledge of the subject. It would have been more difficult for me to do in my early years of teaching.

Students work in groups of two or three, but the boundaries are not fixed, and groups can inter-communicate. The Bechtel Active-Learning Center in the ITLL is designed for this type of activity and has an array of small conference tables. The walls are covered with whiteboards. I have taught in the active-learning mode in a traditional tiered lecture hall. The right architecture definitely helps. I have not had difficulties with group dynamics, but this may be because our students have had many group experiences throughout the curriculum by the time they reach this course. Group work seems second nature to them.

One interesting observation is this:

The group active-learning environment has its own pace and personality. At the beginning of a workshop, students need to check in with each other and socialize a bit. I tried once to discourage this, and it killed the ambiance of the group environment. After the socialization phenomenon, there is a quiet period as students start reading the workshop and trying to figure things out. Gradually, they need to ask each other questions, and the conversation tends to pick up. Eventually, disagreements may occur, and the volume really picks up. As they complete the workshop, it becomes quieter. That is my cue to bring everybody together for a wind-up. If I miss that (approximate) point in time by too much, the socialization picks up again. Variability in the progress of groups smears this pattern some, but my coaching tends to align it. The “noise level” figure below depicts this. An important point is that the personality of the group environment needs to be appreciated by the instructor, and caution should be exercised in tampering with it.



Semester Project Component

I allow students the option of completing a semester project in lieu of the final exam. This project requires about 40 hours of work per student, and students work in teams of two. Only 25% of the class generally elects to attempt a project, the rest preferring to take a final exam.

One reason for the small fraction is that most students in the Control course are taking the Design course concurrently and have to deal with its major project.

Projects are experimental and may require building apparatus, circuitry, and the design and implementation of control systems. Example projects from the Spring 1997 offering of the course are:

- comparing feedback with feedforward/feedback control of a laboratory heat exchanger parameter-scheduled adaptive control of the same heat exchanger
- construction of a new "module in a box" that included motor-speed control, time-proportioned control of an electrical heater, and thermistor temperature measurement
- computer control of the operation of a model railroad, including train sense, speed control, and track switching
- robust PID control of a CSTR with exothermic reaction
- feed flow control for a triple-effect evaporator
- level control for one effect of the same evaporator

All these projects required LabView program development.

Student Evaluation & Reaction

Both observations and formal evaluation provide evidence as to the impact of active learning in the Instrumentation and Process Control course. I will discuss formal evaluation mechanisms first.

I administered an anonymous evaluation questionnaire 6 weeks into the course. This asked three questions:

- a business matter dealing with the preferred date for an evening midterm examination
- list at least three things liked about the course
- list at least three things disliked

Of the 56 questionnaires returned, 48 listed the instructional format ("the workshops") as a liked feature. None listed the workshops as disliked. The frequency of other comments paled to this.

Twelve weeks into the semester, the staff of the College's Integrated Teaching & Learning Laboratory administered a formal group interview to the class in my absence. Student groups propose positive and negative statements about the course that have consensus within the group. These are listed and then voted upon by the entire class. The results are compiled and given to the instructor. This is a widely-used technique at Colorado, and elsewhere. The results of the group interview further confirmed the students' preference for the instructional format, including the laboratory component of the course. There were also many detailed suggestions for improvement of the course.

The final Faculty Course Questionnaire written evaluation was completed near the end of the semester. The results for sampled categories are presented in the table below and compared to recent offerings of the Control course. Although ratings have generally been high in the past, the active-learning-based course produced the highest ratings ever.

Term	Course	Instructor	Workload
Spring 97	A-	A+	6.3
Spring 96	B	A	6.7
Spring 95	B	A-	6.8

In many ways, less formal observations provided for me stronger evidence of the impact of the active-learning instructional format. These included the following:

- Students asked questions in "office hour" consultations that revealed a much better understanding of key concepts in the course than in previous years. This was especially true with regard to the topical area of frequency response with its many challenging concepts (Fourier transform, complex variables, conformal mapping, Nyquist criterion, and so on).
- I assigned, based on my gut feel of where the students were in their understanding, more challenging homework problems than in past years, and students were able to conquer them.
- Students' attitudes toward the course were generally more upbeat.

A very few students do not like the active-learning format. They like the ability to be passive and anonymous in class. Active learning infringes on this. They dislike having to read the book, not able to depend on a regurgitation of it in class. They believe that their God-given right to cut class has been denied. I do not side with them, as if you couldn't tell.

Since the end of the Spring 1997 course, I have received two rather extreme unsolicited comments in emails from students in the course who are now employed. I paraphrase these here:

> *This is the only course of my entire undergraduate curriculum that has been of any use to me in my work.*
>
> *I hired on with several ChE's from other universities. How come they don't know anything about control?*

My colleagues on the ChE faculty do not like the first statement.

My conclusion is that my students are learning better and enjoying it more. Apart from formal assessment results, this is enough to tell me that my considerable effort has been worthwhile.

Bucking the Tide

On the positive side, the leadership of the College of Engineering and Applied Science and the Integrated Teaching & Learning Laboratory at the University of Colorado has been encouraging and supportive of my efforts to introduce active learning into my courses. I appreciate this, and it has helped.

On the other side, most of my faculty colleagues overtly are respectful yet skeptical of my efforts. Covertly, they probably think I've gone off the deep end. I do believe they wish I weren't doing this because it rocks the boat. The tradition of and belief in lecture runs so deep, that I have no illusions of converting many of my colleagues to active learning. A case in point is that both the Applied Data Analysis and Instrumentation & Process Control courses will be assigned to other faculty to teach in the 99-00 academic year when I am on sabbatical leave. I am quite certain they will revert to a traditional lecture format then.

This prospect will not, however, discourage me from returning the courses to active-learning format upon my return.

Acknowledgments

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Bibliographic Information

1. Clough, David E., "The Integration of Laboratory Experience with a Senior Course in Chemical Process Instrumentation and Control", Proceedings of the Frontiers in Education Conference, Champaign-Urbana, 1977.

2. Clough, David E., "Revitalizing Statistics in the Chemical Engineering Curriculum", 1997 ASEE Annual Conference Proceedings, Milwaukee, WI.

3. Jones, James D. and Dianna Brickner, "Implementation of Cooperative Learning in a Large-Enrollment Basic Mechanics Course," 1996 ASEE Annual Conference Proceedings, Washington, DC.

Biographical Information

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