PROBLEM-CENTERED TEACHING OF PROCESS CONTROL AND DYNAMICS

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It has been our experience that undergraduate process engineering students generally find dynamics and process control conceptually difficult, perceive it as peripheral, find it difficult to integrate into their degree program, and as such, tend to find it more of a chore than fun to learn!

In this paper we will introduce a new, problem-based approach to teaching undergraduate dynamics and control and will emphasize its effectiveness in integrating this material into the process engineering curriculum. We also hope to convey our enthusiasm for this approach, which we have found to be tremendously rewarding for both lecturer and tutors.

The subject introduces the dynamics and control of processes by performing a series of exercises and design studies on a selected process flowsheet covering basic instrumentation, synthesis of control schemes, modeling and simulation of process units, feedback (PID) and feedforward controller design, and discrete event control systems. The approach places a greater emphasis on creativity in the areas of control system synthesis and design. The students clearly acquired greater confidence and competence than they did in previous years. Student feedback was dominated by concerns about group dynamics, and it is evident that group dynamics has a significant impact on student learning. This is a difficult problem to overcome, as problem-based learning inherently requires group work and group interaction.

Experiences, observations, and difficulties encountered in the introduction of this approach will be highlighted in this paper, with modifications and recommendations suggested.

OUR "PROBLEM"

Dynamics and control is a compulsory subject taught in the third year of the chemical engineering, environmental engineering, and mineral processing degree programs at The University of Queensland. The subject was scheduled for three contact sessions per week (5 hours) for a 13-week semester. The student workload (including class time) should be approximately ten hours per week.

Upon completion of the course, students should be able to

- *Describe the architecture, components, and cost of instrumentation and control systems*
- *Synthesize control structures for process flowsheets*
- *Develop mechanistic models of, and simulate, relatively simple unit operations*
- *Design simple feedback controllers and feedforward compensators*
- *Design discrete event control systems*

In previous years, the subject was taught in discrete modules, consistent with the above description. Each module was evaluated by the use of assignments (individual) and quizzes. All contact hours were with the whole class, as either conventional lecture or tutorial sessions (where the lecturer presents the problem and then works through its solution).

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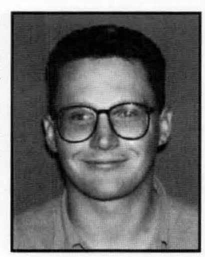

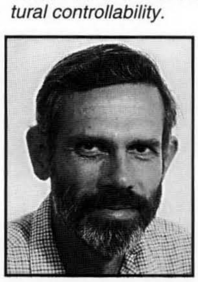

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While this approach was partially successful in achieving the subject objectives, our observations were that

- *Students failed to integrate modules. Once a module was finished, it was forgotten.*
- *Small problems (individual assignments) failed to integrate the subject within their course (mineral processing, environmental or chemical engineering).*
- *The structured nature of the assessment tended to prevent students pursuing their own problems.*
- *There was a clear lack of confidence in dynamic process modeling.*

In summary, students find this material conceptually difficult and generally fail to recognize how dynamics and control relates to their other core subjects; as such, this subject is not normally seen as an enjoyable experience. Furthermore, as the trend is for larger, more heterogeneous classes, it was clear that the teaching strategy for the subject required revision. As a consequence, the approach outlined in this paper was introduced in the second semester of 1994.

OUR STRATEGY

In an attempt to better integrate this subject into the process engineering curriculum, we decided to revolve the subject around a single process and to base the student learning on problems associated with that process. That is, the student learning was to be problem driven and learner centered.

The subject matter, in terms of the objectives and material, was unchanged. The class (65 students) was split into groups of four or five, and the groups were divided into the three engineering disciplines—mineral processing, environmental engineering, and chemical engineering. The objectives were addressed by assigning a series of major tasks for each group. The problems were stated so as to move the students through the several stages of control structure synthesis and control system design. The problems were integrated via the one process, with each group selecting their own process. Each group operated as a 'consulting' company and was required to cost their time. This was an indirect way of assessing and controlling student workload.

The class was scheduled for three contact sessions per week (Monday, Wednesday, and Friday). Since our objective was to orient the teaching around the problems, each week we intended to introduce and discuss concepts and analytical tools that the students were at that time trying to use for their process.

The Monday class was essentially a lecture (to the entire class) that attempted to provide the students with the tools they would need to progress with their problem. Small example problems were used for demonstration.

The second period each week (Wednesday) was the most critical contact time. The class was divided into three smaller classes (consisting of four groups each). Our objective in these sessions was to assist the groups in implementing the material (that had been presented on Monday) for their specific process problem; For ease of discussion, this session will be called the tutorial session.

The tutorials were facilitated by postgraduate students and were tightly structured. While we are aware that this is not ideal for an orthodox problem-based course, it was necessary due to time and resource constraints. The lecturer and tutors met prior to each session.

On average, the tutorial sessions began with a short review of the lecture material and proceeded to outlining what was required within the session. Because each group was studying a different process, it was important for the groups to present their work to the other groups—this was an important part of the learning process. Marks were not allocated for tutorial attendance, but attendance was high (90-95%).

The Friday period was used for a 'standard' lecture to the whole class. The aim of this session was to review the work performed in the tutorial session and to address specific problems and questions raised by the students. Due to time constraints, this session was sometimes used for additional lectures.

FOUR WEEKS IN THE LIFE . . .

We must admit to feeling somewhat challenged to adequately describe the experiences and feelings of students in this class. We will attempt to guide you through the first four weeks of the subject—our objectives, and the students reactions to lectures, tutorials, and problems.

Week 1

Lecture
- Hello!
- Introduce resource materials. The major resources used were a subject study guide, a process control textbook (Seborg, et al.[1]), a MATLAB software package, and a PID controller tuning experiment.
- Clarify the approach to teaching the subject. Why are we teaching in this way?
- Students are separated into groups of 4-5 and instructed to "select a process" to study. The only guidance provided was that there should be approximately 10-20 units, multiple phase unit operations, and recirculating inventories.

Tutorial
- No formal tutorial session. All groups are invited to meet their tutor and discuss process selection

Reaction
- Students tend to display a lot of interest in this first week. They are confronted with a different approach for learning, and most are genuinely supportive.
- Most groups will have no difficulty in selecting a process.

Week 2

Lecture
- Subproblem 1 is handed out (see the Appendix)
- Introduction to mass and energy inventory control (the basic tools for addressing subproblem 1).

Tutorial • Each group presents their process to the rest of their tutorial class (each class consists of four student groups). We strive to emphasize the importance of understanding their process at this early stage.

Reaction • At this stage, the students are starting to feel a little concerned—they have a problem that they do not entirely understand, and they feel frustrated.

Week 3

Lecture • The lecturer demonstrates mass and energy inventory control loop pairing through several examples of unit operations.

Tutorial • Each group presents a control system design for one unit on their flowsheet.

Reaction • Panic! The report is due in one week; the students can now define the problem and realize what is required.

Week 4

Lecture • No formal lecture.

• No formal tutorial, although the students are encouraged to privately consult with their tutor.

Reaction • The first report is submitted.

The subject is taught via four subproblems. Table 1 summarizes each problem in terms of our objectives. An ammonium nitrate process is employed to provide an example of specific outcomes for each problem (see the Appendix).

The problems are the major form of assessment (group reports). A system of peer assessment was adopted for the problems.[2] Upon submission of a group report, each student was required to assess the effort of his or her colleagues via an assessment form that was handed out to the students (see Table 2). The responses for each group are compiled and an average-effort rating for the group is obtained. Each individual mark is then obtained by

$$\text{Individual mark} = \text{Group mark} * (\text{Individual effort rating}/\text{Group effort rating})$$

We also included two pieces of individual assessment: a quiz on dynamic modeling and a final examination. The reasons for doing this were to reduce student concerns over the peer assessment, to address our concerns about our ability to assess students via group projects and peer assessment, and to enable a comparison of performance with previous years.

The group project was the major focus, however, and the quiz and examination were restricted to assessing individual understanding of the group-project activities.

IS THIS AN EFFECTIVE APPROACH FOR TEACHING DYNAMICS/PROCESS CONTROL?

Formal subject evaluation, via student questionnaires, was performed by The University of Queensland Tertiary Educational Institute. The subject ratings (1-7; 7 high) for 1994 and 1995 were 4.9 and 4.6. The ratings for the previous years, prior to the subject change, were 5.2 and 4.7, respectively. Student feedback was dominated by group dynamics; an important outcome in itself. A summary of students comments follows.

- *"Group projects are an excellent idea. However, there is a problem with some people who do not pull their weight."*
- *"Group work sucks—in industry if you don't work properly you get fired. At Uni if you don't work properly, everyone gets shafted!"*

TABLE 1
Objectives for Each Problem and Example of Resulting Outcome

Our Objectives		*Ammonium Nitrate Process Outcomes*
Develop an understanding of the process • Synthesize a control system structure • Develop an appreciation of control system architecture • Determine basic instrumentation costs • Prepare a P&I diagram • Develop an appreciation of the interaction between design and control • Develop project management skills. →	**Subproblem 1** Control Structure Synthesis ↓	→ 22 control loops were specified to control the mass and energy inventories • DCS architecture was recommended • Quality control was specified for the ammonium nitrate product and both waste streams • P&I diagram showing basic control loops with sensors and actuators • Preliminary control system costing • Discussion of design/control interaction.
Dynamic model synthesis • Linearization of nonlinear model • Perform step-test identification • Dynamic simulation • Perform sensitivity analysis. →	**Subproblem 2** Dynamic Modeling and Simulation of One Unit ↓	→ The loop reactor was modeled as a CSTR and evaporative separator in series. The model consisted of 10 ODEs and 20 algebraic equations. The reactor was simulated in MATLAB, with step responses and sensitivity analyses performed. The effect of various design options was also investigated.
Design and tune PID controllers • Design a (static and dynamic) feedforward compensator • Analyze control system performance. →	**Subproblem 3** 'Simple" Controller Design ↓	→ P, PI, and PID controllers were evaluated for reactor temperature and pressure control. Yuwana-Seborg, ISE and ITAE tuning formulae were investigated. A feedforward regulator was implemented for nitric acid feed flow disturbances.
Develop an understanding of discrete event control strategies as opposed to all previous work, which was on a continuous process. →	**Subproblem 4** Discrete Event Systems	→ GRAFCET diagram for the start-up and shut-down of the reactor.

- *"Include more control practicals."*
- *"Group work is very frustrating!"*
- *"Flowsheets should be selected to be of equal difficulty."*
- *"Group work was very difficult when you have one dominant group member. I suppose it comes down to group dynamics and my problem of not talking about my problems with other group members."*
- *"Make groups have a maximum of 4."*
- *"Provide more support for groups struggling with their models."*

It is clear that working in groups polarized student opinion. When teaching this subject the second time (second semester 1995), we placed more emphasis on group dynamics and introduced the students to the problems experienced in the previous year in the naive hope that they might learn from previous mistakes. Figure 1 clearly illustrates that this was far from successful. This is a difficult obstacle to overcome, as problem-based learning inherently requires group work and group interaction. We have yet to resolve this problem satisfactorily.

It is also apparent from the feedback that some students were uncomfortable with the open-ended nature of the subject and had gained little appreciation of why we adopted a problem-based approach:

- *"Don't be so slack . . . use more of the lecture time available to teach us."*
- *"Do not be so lazy. If you are allocated lecture times, use them!"*
- *"When you are teaching things to people for the first time, they have to be explained very thoroughly."*

TABLE 2
Assessment Form

NAME: *Paul Lant*	**GROUP MEMBERS** *Bob*	*Marc*	*Lisa*
Project mgt. and organization	2	5	4
Writing & compiling report	2	4	4
Data gathering and lit. survey	2	5	5
TOTAL (out of 15)	6	14	13

Minimal Contribution	Satisfactory Contribution	Outstanding Contribution
1	3	5

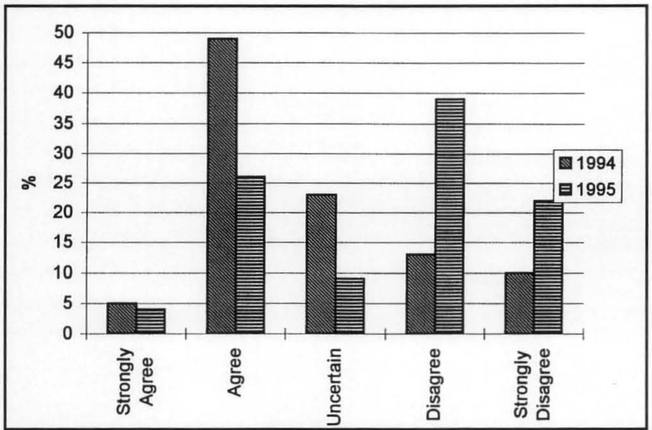

Figure 1. *Questionnaire response to the statement, "I enjoyed doing the group project."*

It is a sad reflection on our broader educational system that intelligent, 20-year old, engineering undergraduates are uncomfortable with ill-defined problems, threatened by something new, and fail to accept responsibility for their own learning. If anything, this fortifies our belief in this approach. But it is clear that we need to expend more effort in gradually introducing the students to the subject.

How well does this approach address the driving forces for change? We shall address each in turn.

To what extent did this approach integrate dynamics and control into the degree program? • This was the single most important aspect of this subject formulation. Students were forced to think about dynamics and control within the framework of the whole process. It was incredibly rewarding to see students actively considering control and design issues simultaneously.

Did the subject address the different demands of different groups of students? • The group cases enabled students to learn by employing control and modeling skills on a process of direct interest to them. The processes investigated were extremely varied and included:

Mineral Processing Groups: Updraught lead sintering • Lead-zinc concentrator • Lead concentrator

Environmental Engineering Groups: SO_2/NO_x Flue Gas Cleanup • Wastewater treatment • Combined cycle power generation • Brewing

Chemical Engineering Groups: Ammonium nitrate • Whey fermentation to ethanol • Formaldehyde • Carbon tetrachloride • Sugar milling

We believe that the scope of the problems investigated would only be achieved by adopting this type of problem-based approach.

Is this class more competent, and confident, with process control and dynamics? • The work submitted was of a very high standard (for what were 'average' classes). Significant improvement over previous years was observed. The motivation and commitment of the students was high, as reflected in the tutorial attendance and well-presented reports. Tutorial attendance was not compulsory, and yet was in excess of 90%.

CONCLUSION

While it is always difficult to obtain an absolute measure of 'improvement' in a subject (due to the lack of a control), we are confident that this approach serves to emphasize and enhance key process control skills. The problem-based approach to teaching dynamics and control presents students with a real, yet ill-defined, challenge. Creative skills, such as design and synthesis, are emphasized. Furthermore, it is also amenable to larger, more heterogeneous classes, which appears to be an inevitable trend in Australia.

For anyone interested in using this approach, we offer several recommendations for consideration:

- *Restrict groups to 3 or 4 people.*
- *Do not underestimate the negative effect of group dysfunctionality. As such, it is critical to pay significant attention to group dynamics and project management (review and discussion sessions during the semester).*
- *Use mixed tutorial sessions to encourage interaction. In our case, we mixed mineral processing, environmental engineering, and chemical engineering groups in one tutorial group.*
- *Dynamic model synthesis and simulation tends to be a difficult conceptual step for most students. It is important, therefore, that this particular subproblem be tightly controlled by the lecturer and tutors.*
- *Do not attempt to use this approach without adequate resources—in particular, sufficient good tutors. The role of the tutors cannot be understated. It is important that they are aware of their role and that they are competent of facilitating and guiding their groups through the subject. Should the tutors be 'experts' in the field? This question has raised significant debate in the broader field of problem-based learning. But when faced with tight time and resource constraints (we cannot afford to have a ratio of one tutor per group of four students), we believe that expert tutors are a necessity.*

Finally, while we must admit that the open-ended nature of the problems provides lecturer and tutors with more challenges and is unquestionably more resource intensive, our brief experience indicates that it is a more rewarding and fun approach for teaching dynamics and process control.

ACKNOWLEDGMENTS

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REFERENCES

1. Seborg, D.E., T.F. Edgar, and D.A. Mellichamp, *Process Dynamics and Control,* Wiley & Sons, Brisbane (1991)
2. Conway, R., A. Kember, A. Sivan, and M. Wu, "Peer Assessment of an Individual's Contribution to the Group Project," *Assess. and Eval. in Higher Ed.,* **18**(1), 45 (1993)

APPENDIX

Example Problem

The Stamicarbon process for the manufacture of ammonium nitrate is representative of the size and complexity of the problems chosen (see Figure 2).

Subproblem 1 • Your group is to act as a consultant to Multinat Pty Ltd. Multinat is the contractor responsible for designing and constructing PROCESS. Multinat has subcontracted the process control system design to you. Multinat is performing the project management.

In order to coordinate all subcontractors, Multinat requires the following information in your report: number and type of control loops; instrumentation (sensing elements, controllers, and final control elements); and costing.

Multinat is not familiar with process control. It is, therefore, imperative that you can justify your recommendations. Your report must include a description of the process, with particular emphasis on the process operating objectives and constraints (what are they?).

This initial contract with Multinat is worth $10,000. It costs your organization $100/hour for labor (it is important that you accurately record, and cost, your time). That is, each 1-hour meeting of your team of 4 people costs $400. It is, therefore, important that each meeting is efficient, with tasks clearly defined and allocated. You must identify what the tasks are, who will perform them, and by when (an action plan). You should include a memo to your manager stating the cost of the study.

You are aware that Multinat will require further control work to be performed on this project. The objective for your project team, therefore, is to generate a report good enough to win future contracts, while also maximizing the profit to your company. Do not miss any opportunity to impress Multinat. Comment on any areas where design modifications may be beneficial. Offer alternatives when possible. ❐

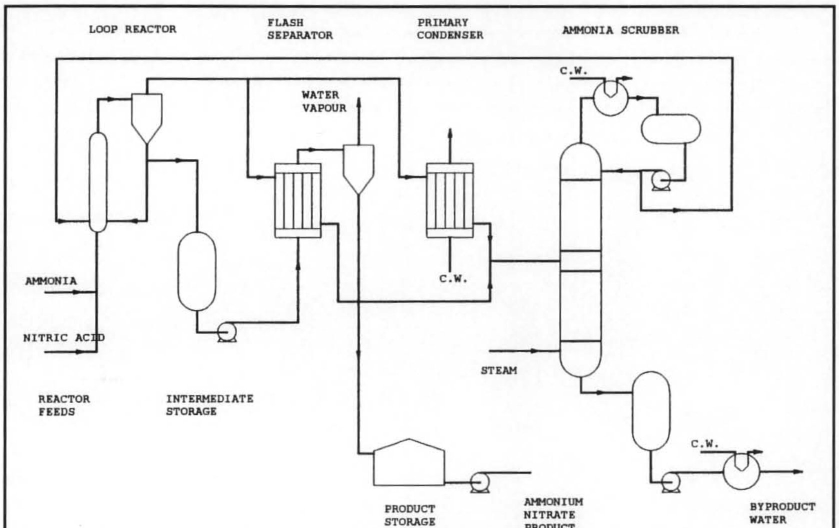

Figure 2. *Ammonium Nitrate Process (A selected case study.)*