

8 Years Of Experience In Teaching Process Dynamics And Control With Control Station® Software

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The paper describes all the steps of a teaching activity dealing with Process Dynamics and Control and focused on the students' use of the Control Station® simulation software. After a short software description, the paper discusses the methodology developed for coupling theoretical lecturing and practical PC-lab class, the way of involving students and the use of an interactive software environment to present automatic control of illustrative process plants. These latter comprise unit operations and simple equipment from chemical, biochemical, pharmaceutical and food industries as actual examples of abstract systems and mathematical formalisms introduced for studying processes in the context of dynamics and control. Two Project Works, which were developed by students using Control Station® and discussed by them, are presented as examples.

The outcome of this 8-year teaching experience is analyzed on the basis of the number of Project Works annually delivered, the auto-evaluation tests, the final exam scores as well as the relevant answers yearly provided by the students through the Course Evaluation Forms. The final statistical results are positive.

1. Introduction

Process control is very often faced by students in a mechanical way, especially in the part concerned with simulation. Majority of students, when they have to make the model of a process system, usually apply in repetitive way what they have already got in class. In general, some main features generally ignored by the students are given in the following: i. ignoring what the process system to which they apply the control is for; ii. why it is necessary to control a variable rather than another one; iii. what consequences an uncontrolled system could bring. Such a type of study creates a sort of ambiguities, normally a superficial learning; as a consequence, the contents of the discipline are destined to be easily forgotten.

On the other side, the conventional approach to lecturing tends to present process plants as abstract systems and/or mathematical objects. It is a common practice that the actual unit operations and process equipment in chemical, biochemical, pharmaceutical and food industries do not directly come in contact, and their dynamic behavior or response to control actions are not visualized (Bequette et al., 2000); for further example, Silverstein (2005) stated: "The mathematical focus on process descriptions in the Laplace domain has made it appears to students as a course distinct from 'regular' chemical engineering".

The authors have already been working on the subject, both on the simulation and the experimental side. They developed a Graphical User Interface in Matlab® for students facing the dynamics and feedback control of simple chemical reactors as well as non-linear bioreactors (Cosenza and Miccio, 2017). Later, they took advantage of the acquirement of a lab-scale educational apparatus (i.e., the MPS® PA Compact Workstation) for process measuring, monitoring and control, and used it for both lab class demonstration and students' Bachelor thesis work (Miccio et al., 2019). The recourse to lab-scale didactic facilities is widespread: Topçu (2017) reported about training engineering students on the practical control of a demonstration electro-hydraulic

power system, along with related PC-based simulation. Ramos et al. (2017) built a three-tank facility and trained students on multivariable MPC through it.

The Didactic Council of Chemical Engineering of the University of Salerno has decided since 2003 to adopt a simulation software for class as well as individual student's use as a teaching aid for process dynamics and control. The choice was the Control Station® software. Therefore, the Council has been purchasing an annual software license (for 50 students) for more than 15 years. In the last 8 years, the Control Station software and tools have been systematically used in the class of Process Instrumentation and Control of the degree course in Chemical and Food Engineering at the Bachelor level.

This paper briefly presents two examples of Project Work activities, comprising qualitative and quantitative evaluation of the dynamic response to common inputs at either open or closed loop, fitting of a First Order Plus Dead Time (FODTP) model and tuning of the PID controller. Moreover, the paper discusses this 8-year experience by analyzing the exam scores, the students' outcomes from the Course Evaluation Forms, the statistical results of student's **auto-evaluation** tests. This effort has been done annually throughout the period.

2. Software description

Since about 20 years, Control Station (controlstation.com, 2020) provides software (formerly Control Station®, recently Loop Pro®) and training tools for academic education and professional training in process dynamics and automatic control. The Loop Pro® software helps instructors to put key concepts into a clear context. Moreover, it is equipped with an array of simulation tools for the users and makes the learners having "hands on" dynamics and control problems in a guided way with an agreeable user's interface. The software also provides a comprehensive e-book (Cooper, 2008).

To cultivate a true understanding, the Control Station software provides access to over 15 Case Studies as simplified synoptics of common industrial processes (e.g., Gravity Drained Tanks, Pumped Tank, Jacketed Reactor, Heat Exchanger), with simulations for open and closed loop (e.g., set point tracking and disturbance rejection) dynamics; both integrating and non-integrating processes are included. For each of the Case Studies a simple and interactive synoptic screen is provided to the user. The Design Tools module adds a dynamic process modeling and a PID controller tuning utility, delivering data editing, model selection, model fitting and controller selection. In addition, the Custom Process module complements the previous ones by allowing the users to implement their own linear dynamic problem and enter a 'what if' environment.

The software can import and handle true process data. Afterwards, it enables linear fitting dynamic modeling (e.g., FOPDT) for the data, then it conveys optimal tuning of a PID controller for the actual process from which data was generated. For example, this approach has been recently followed by Marra et al. (2020).

3. Methodology

Every academic year, the following procedure has been applied by the lecturer:

- the Control Station software is introduced to the whole class;
- fundamentals, concepts and methodologies coming from theory (e.g., lectures) are shown as implemented or running in the software;
- components typical of the feedback control loop (e.g., PID regulator, sensors, final control elements, actuators) are revealed as present in the pre-built Case Studies;
- some key examples are used with students having "hands on" directly on PCs in a lab class;
- students are invited to submit a Project Work based on the software use as an elective task, which provides an additional score (up to 3 points out of 30) to the mark attributed by the lecturer to the conventional exam;
- each Project Work delivered by a student is reviewed and publicly discussed by the lecturer;
- each student submitting a Project Work undertakes a simple **auto-evaluation** test, just consisting in attributing a numerical grade to such a teaching activity carried out by the lecturer;
- the whole class fills in the mandatory Course Evaluation Form provided by the University Quality Board; more specifically, students answer questions referred to lab class practice and innovation in teaching.

4. Project Works

4.1 Binary distillation column

The Project Work questions were:

1. recognize disturbances, set point, controller output and manipulated variables on the process synoptic
2. simulate the open loop dynamic response
 - a. one of the disturbances; b. one of the controller outputs
 - c. one of the disturbances; d. one of the controller outputs

- discuss the open loop responses and propose a general comparison

The layout of the distillation column was shown in a simple process synoptic (see the screenshot in Figure 1a).

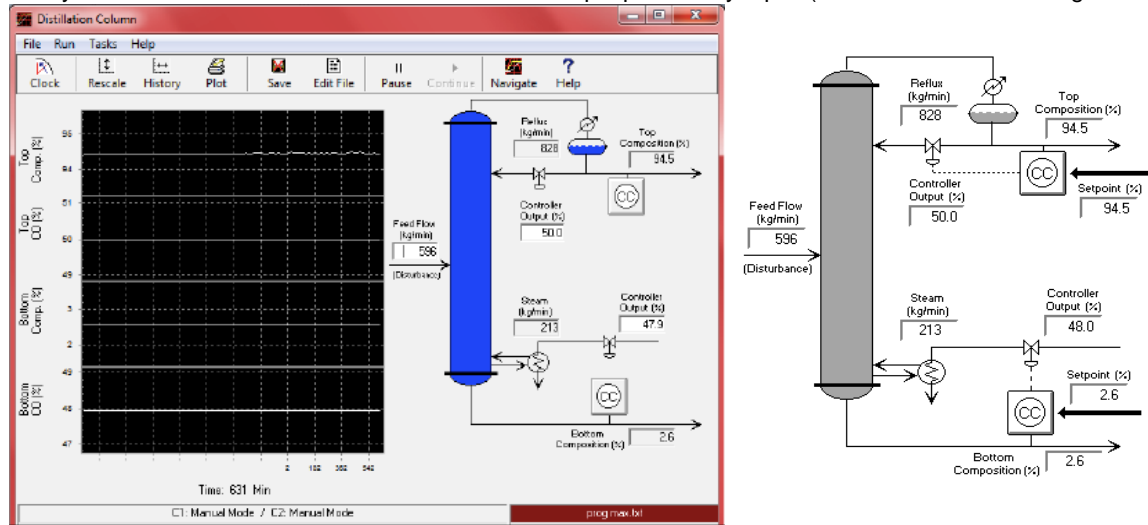


Figure 1: Simple synoptic of the binary distillation column as a Case Study in Control Station: a. open loop; b. closed loop

On initial stage the student was asked to understand the control structure made of two distinct control loops, the first one on the top composition, the second one on the bottom composition, both with reference to the light component. They represented the **controlled variables**. Then, the student had to distinguish the key process variables and recognize their role; they are the two **set points**, of course applied to the above mentioned top and bottom compositions; one **disturbance** identified in the feed rate of the liquid to be distilled; two **manipulated variables** recognized as the reflux flow rate from the top condenser and the steam rate to the bottom reboiler; two corresponding **controller outputs (CO)** acting on the reflux valve and on the stem valve to reboiler, respectively. It is worth noting that **CO** is non-dimensional and expressed in the range 0-100%. For the sake of shortness, only one answer is reported here with reference to the question 2.c.

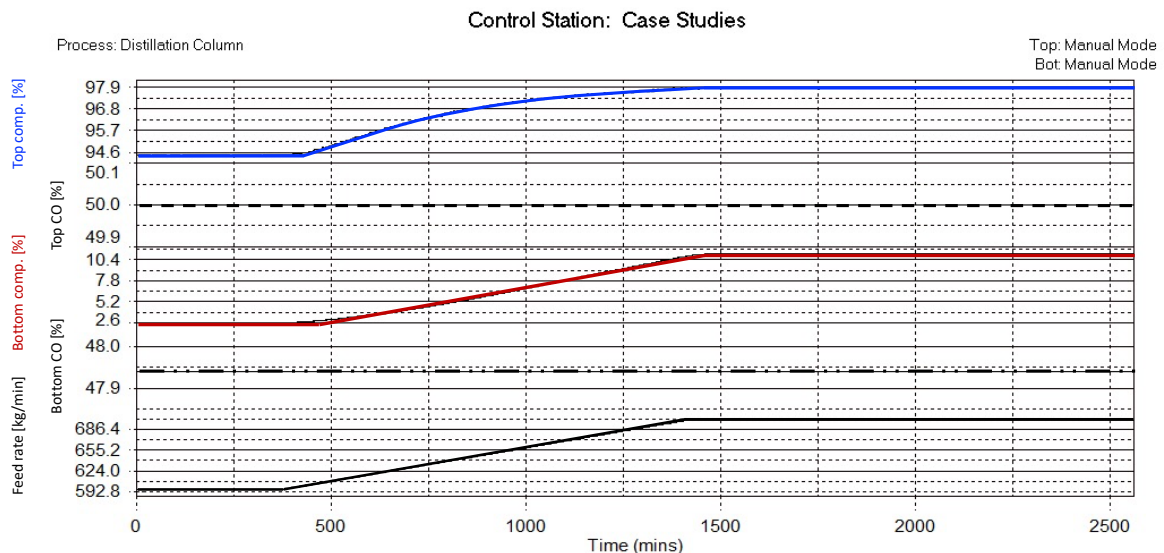


Figure 2: Time domain response of the top and the bottom composition at open loop following a **limited ramp** variation of the disturbance (feed rate, lower part of Figure)

In order to simulate the system for open loop response to a **disturbance** variable, the feed rate was to be changed. By double-clicking the value field of disturbance, the student opened an auxiliary window and accessed the tab dedicated to "ramp", where he programmed a change in the value of the disturbance from 596

to 700 kg/min with a ramp rate set at 0.10 kg/min² in the dedicated input fields. By clicking the “Done” button the student started the simulation of the variation induced by the disturbance, while keeping the **controller outputs** constant. The dynamic response was plotted in a real-time chart within the window of the synoptic and made also available in an external customizable graphical window, which is reported in Figure 2.

In a nutshell, students’ main achievements were

- i. observing the self-regulating behavior of a simple but still realistic process system;
- ii. handling input variables different in their role;
- iii. testing distinctive types of forcing function.

4.2 Pumped Tank

The Project Work questions were:

1. simulate the open loop response to a step-down change in the disturbance variable, as small as you like
2. return the simulated system to the initial conditions
3. perform the optimal tuning for an ideal PID controller
4. simulate the closed loop response to a step-down in the disturbance variable, of the same size as above
5. compare the results with the previous open loop response and comment on them

The layout of the pumped tank was shown in a simple process synoptic (see a screenshot in Figure 3a).

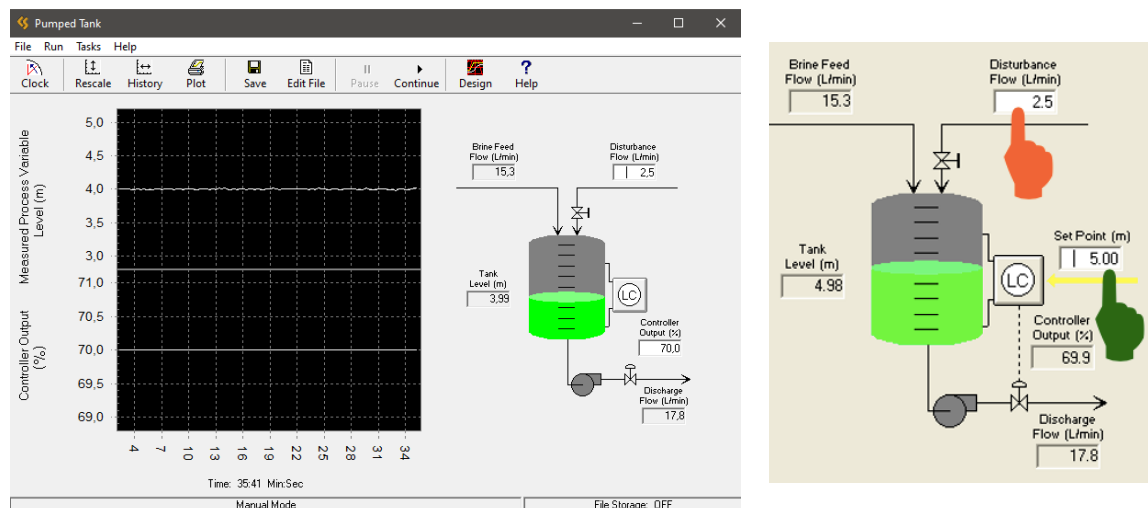


Figure 3: Simple synoptic of the pumped tank as a Case Study in Control Station: a. open loop; b. closed loop

First of all, the student checked the time domain response at open loop and was immediately confronted with the BIBO instability: actually, the pumped tank is represented by a purely capacitive or integrating system, which is known to be affected by marginal stability (Stephanopoulos, 1984). The above issue was documented by the student through the plot in Figure 4a, which reports the step-down change of the top-right input flow rate to the tank from 2.5 to 1.5 L/min at the arbitrary time $t=10$ min (programmed within the auxiliary window for disturbance) and the consequent variation in the level, with a constant-rate fall to zero (i.e., emptying of the tank).

Then the student applied the procedure (not reported here for the sake of shortness) aimed at building a FOPDT-Integrating fitting model of the time-domain response to step and implementing a PID controller properly tuned with IMC formulas, in a guided way within the software itself.

Finally, the student answered the question No.4 and produced the diagram in Figure 4b, where the same step-down change in the disturbance was set at the arbitrary time $t=17.5$ min and the set point (see the yellow line) tracking behavior was observed for the controlled variable (see the white noised line representing the level).

By answering the question No.5, the student commented that the feedback control was successful in turning a marginally stable system into a BIBO stable one at closed loop. Further, the adoption of a PID controller eliminated the offset because of the integrating action and led to a prompter response without excessive oscillations because of the stabilizing derivative term, enabling the PID to have a comparatively wider range of controller gain values than in the case of PI.

Consequently, the major achievements of the student in the Project Work were as below:

- iv. observing the non self-regulating behavior of a simple but still realistic process system
- v. building a linear FOPDT-I model approximating the dynamics of an integrating system;
- vi. tuning a PID controller;
- vii. mastering the issue of set point tracking

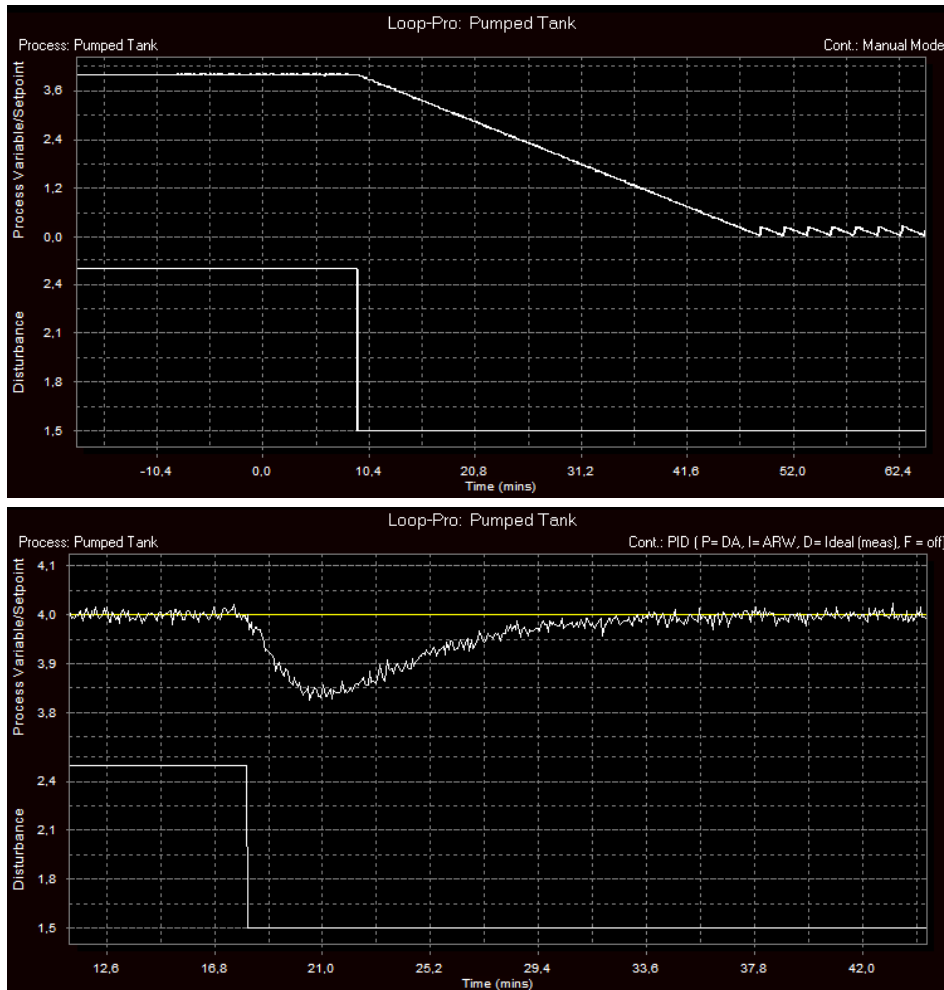


Figure 4: The level in the pumped tank as the time domain response to a step-down variation of the disturbance (input flow rate): a. open loop; b. closed loop

5. Evaluation

The Figure 5 presents simple statistics concerning the reported teaching activity.

Figure 5a refers to the whole class. While the number of students attending the class has been roughly increasing through these 8 years (see the orange line in Figure 5a), the introduction of a PC-based lab class activity within the course schedule has been always rated as an innovation (see blue bars in Figure 5a) by the upcoming students. As a complementary information, the satisfaction expressed by the students for having such a teaching activity as a PC-lab class (see grey bars in Figure 5a) always remained above 70%, although with an oscillating pattern. In spite of the increasing number of students attending the class, the corresponding number of students actually undertaking the Project Work as an elective task has been decreasing, although with an oscillating pattern (see blue bars in Figure 5b). This can be partly attributed to external reasons, for instance a trend of students to speed up their career progress at Bachelor level and hence to skip "elective" tasks. This is a proven fact, which has been observed by the Didactic Council of Chemical Engineering of the University of Salerno. On the other side, the auto-evaluation results from the students undertaking the Project Work remained good and exhibited a detectable trend to grow in the last three years (see orange bars in Figure 5b). In contrast, an increasing trend appears in the last years for the (average) score attributed by the lecturer to the students' Project Works (see the grey line in Figure 5b). This can be partly attributed to the fact that students undertaking the Project Work, although reduced in number, were more motivated to work successfully.

6. Conclusions

In a sequence of 8 academic years, the subject of Process Dynamics and Control at the Bachelor level of Chemical and Food Engineering studies has been structured by coupling theoretical lecturing and practical PC-

lab classes, these latter being based on the students' use of the Control Station® simulation software. Students have been involved not only tackling with unit operations or simple process equipment simulated by the software but also elaborating individual Project Works requiring a smart and interactive software use. This didactic approach allowed enlightening the subject in a practical and convincing way, and ensured very good results from the students' side by their substantial involvement and commendable performances.

This multi-year outlook appears very interesting in view of opening a new route for the switching of the teaching activities toward an “active learning” approach at the University of Salerno. Moreover, as a follow-up of the reported experience, cooperation proposals on teaching are now being pursued with other universities and educational institutes in Europe. As a first instance, a collaboration in this teaching area has been established with the Department of Chemical Engineering at the University of Split since two years ago and reciprocal teaching assignments are now in progress.

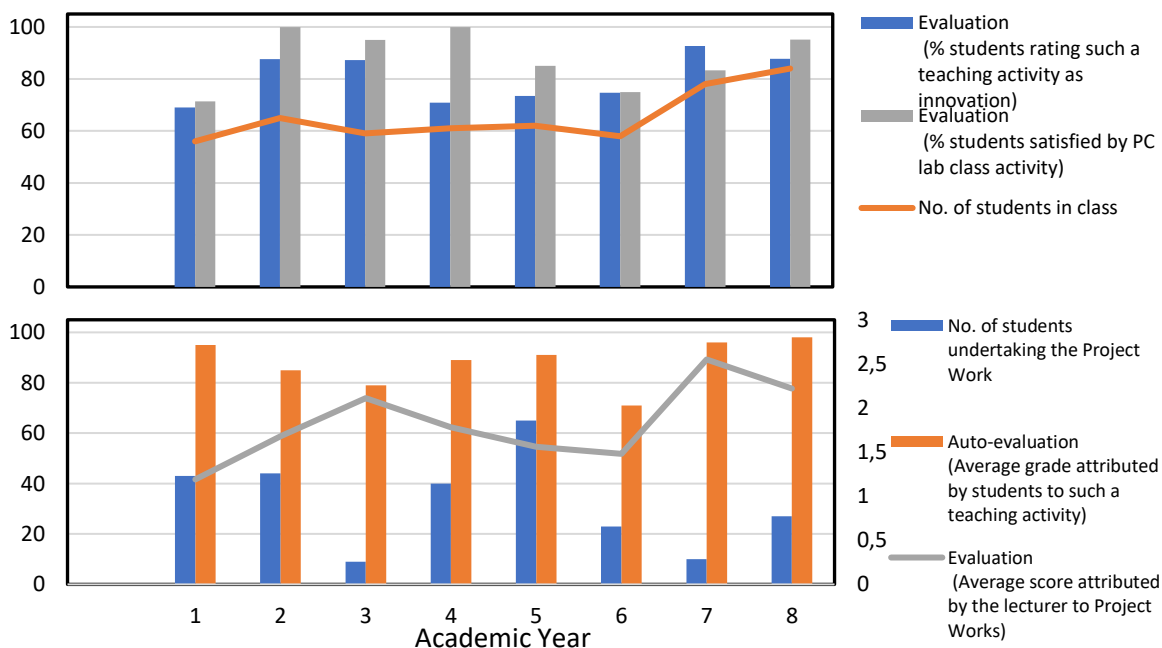


Figure 5: Results of students' tests in each academic year: a. percentage of satisfied students; b. evaluation and auto-evaluation marks of students undertaking the Project Work

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