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An Educational Workshop for Effective PSE Course Development

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Abstract

An educational workshop for developing Process Systems Engineering (PSE) courses will be held during ESCAPE-33, following the model workshop that was run during the CAPE Forum 2022 held at the University of Twente, in the Netherlands. This 3-hour workshop distributes the participants into four teams working together to develop the outline of a course on a novel application area in PSE motivated by a selected plenary or keynote talk at the conference, with each team led by authors of this contribution. This paper provides an overview of the approach used in the workshop for the effective development of a PSE course.

Keywords: PSE education, course development, learning objectives.

1. Introduction

From 14-16 September 2022 a workshop on developing Process Systems Engineering (PSE) courses was held at the CAPE Forum 2022 at the University of Twente in the Netherlands (www.pse-nl.com/index.php/cape-forum-2022). Working in teams, participants of the forum with different backgrounds developed education plans for a complete course on one of four selected subjects: Carbon-neutral PSE, Sustainable bio-based PSE, Energy efficient PSE, and Artificial Intelligence (AI) in PSE. These are representative novel application areas described by Lewin et al. (2022) as suitable emerging fields that offer new horizons to students from the basic areas of process design, process control and numerical methods, and, of course, rely heavily on them as foundations. These topics are also fully in line with the recently described PSE developments in industry and academia (Kiss and Grievink, 2020). The specific topics selected in CAPE Forum 2022 were inspired by the four keynote talks delivered at the meeting and the team leaders for the course development were the four keynote speakers from industry and academia (Bart Wentink, Ellen Slegers, Stefan Krämer, and Artur Schweidtmann).

The workshop was held in two sessions. In the first session, each team worked on developing learning objectives and a syllabus for the entire course. They also proposed more detailed learning objectives and content for at least one week of activity of the course. In the second session, each team developed suitable activities for students for each of the weeks of activity specified in the first session. Each of the courses developed relied on the *flipped classroom* paradigm (Lewin and Barzilai, 2022; Lewin, 2022), in which every week of class activity is divided into three sequential phases: (1) *preparation*, in which students prepare for the week's activities by completing online lessons consisting of a series of short video clips and associated quiz questions that test comprehension; (2) *class meeting*, in which students improve their understanding, comprehension, and capabilities by tackling open-ended exercises and discussion mentored by the teacher, and (3) *active tutorial*, in which students solve exercises on their own or in small groups with their peers, mentored by the course staff. For more details, the reader is referred to the referenced papers, and the YouTube video clips mentioned in Section 3.

2. Course Development Steps

A systematic framework for course development follows the following top-down approach:

Step 1: At the highest level, one needs to answer the question: "*What do I want my students to learn and why*?" In other words, to specify what skills and attributes students need be able to demonstrate on successfully completing the proposed course. These are best defined in terms of learning objectives. For example, for a typical 13-week course on *Process Dynamics and Control* (equivalent to 5 ECTS), the course learning objectives would be divided into those concerning dynamic modelling and those concerning control design, defining what a student needs to exhibit on successfully completing the course:

Process modelling (Weeks 1-6):

L01: Capability to model dynamic response of processing systems using material and energy balances

L02: Ability to linearize models and generate transfer function approximations

L03: Ability to generate overall transfer functions from block diagrams

L04: Ability to analyse the transient response of linear systems

Process control synthesis (Weeks 7-13):

L05: Frequency domain analysis capabilities, enabling transition between Laplace, frequency, and time domains

L06: Stability analysis capability

L07: Knowing how to tune PID controllers effectively

L08: Capability to synthesize feedback control systems to meet closed-loop performance specifications

L09: Capability to design effective cascade and feedforward control systems

Step 2: Identify the best teaching approaches for the type of learning you want. For efficient learning, we recommend active learning strategies. This implies freeing some or all of the contact student-staff time to allow students to get involved in staff-assisted problem-solving. An established way to do this is by *flipping the classroom* (Lewin, 2022), which moves some or all of the lecture material to student online self-study activities. An alternative approach would be to reduce the volume of lecture material, and indeed, any approach that frees some student-staff contact time for practice is appropriate.

Step 3: Select the course content, organized as a weekly schedule, in which each week is driven by its learning objectives. For example, for the process control course, the weekly schedule could be as shown in Figure 1. Therein, specific learning objectives are defined for each week. For example, in Week 10, the learning objectives would concern the Root Locus method:

On completing week 10 of the process control course, the student should be able to:

- Sketch the root locus, given transfer functions for a process and its controller,
- Sketch the output response of a controlled process, given locations of closed-loop poles on the root locus, and
- Use the root locus to design a controller, given the transfer function of the process to be controlled, to meet the desired closed-loop response specifications (e.g., overshoot and settling time).

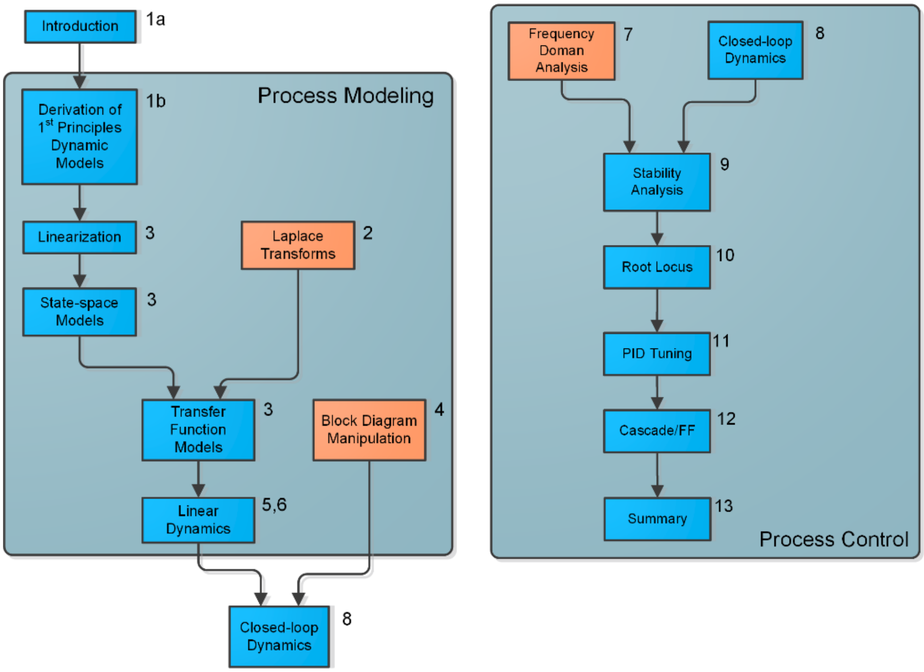

Figure 1. Weekly schedule for a course on process control; numbers in the diagram refer to weeks in the course.

Step 4: For each week, develop student assignments, projects, and class activities so that all the learning objectives are practiced by the students, with repeats as necessary. This is by far the most important content of the course, as it defines the mechanisms by which students will "learn by doing." Some of the activities should be designed to be guided activities (e.g., open-ended problem solving in class meetings, guided by the instructor), which other activities are designed to be for students working alone or in groups. An example exercise for Week 10 of the process control course that tests accomplishment of all three learning objectives would be the following:

Given the open loop transfer function: $PC(s) = \frac{K_C(s+2)(s+4)}{s(s+1)(s+5)(s+10)}$

(a) Draw the root locus for *PC*(s).
(b) Determine the value of K_C that will give the fastest possible closed-loop response with no oscillations.
(c) Sketch (qualitatively – there is no need to compute the response) the closed-loop response to a unit step change in the setpoint, with the value of K_C as determined in part (b).

Step 5: No work on course development is ever final. One should always make an effort to improve the course plan with class experience and feedback.

3. Outline and outcomes of the CAPE Forum 2022 Workshop

3.1. Workshop activity

In the spirit of "flipping" the course, the Forum participants were invited to review the short videos describing how the flipped class is used to teach PSE subjects before attending the CAPE Forum:

Webinar talk (14 min): www.youtube.com/watch?v=O3hoSlYaGo4

ESCAPE-31 Keynote (28 min): www.youtube.com/watch?v=b6w6mqSPxp0

The workshop was organized with three points of contact during CAPE Forum 2022. Splitting the workshop into three points of contact gave the opportunity for group members to get together informally and discuss course content during the entire forum. The three points of contact were:

1. 15th September 2022, morning – Participants were distributed into one of the four topics by a suitable color code on their badges. A 5-min announcement introduced the workshop. Each of the four teams was asked to prepare an outline for a new course in the following subjects:
   Topic 1: Carbon-neutral PSE, led by Bart Wentink and Leyla Özkan
   Topic 2: Sustainable biobased PSE, led by Ellen Slegers and Meik Franke
   Topic 3: Energy efficient PSE, led by Stefan Krämer and Pieter Swinkels
   Topic 4: Artificial intelligence (AI) for PSE, led by Artur Schweidtmann and Ana Somoza-Tornos
2. 15th September 2022, afternoon – First 90-minute session. The workshop presenter introduced the activity and initiated a hands-on session in which the four groups worked on developing each of the courses (**Steps 1** and **3**), led by one of the keynote speakers. This session was positioned after the last of the four keynotes.
3. 16th September 2022, afternoon – Second 90-minute session. The workshop presenter introduced a hands-on session in which the four groups worked on **Step 4**, developing activities for students appropriate for at least one of the detailed weeks planned in **Step 3** for the first hour, each group being led by one of the keynote speakers. In the last 30 minutes, the groups presented their course

plan outlines to all participants and received immediate feedback from the instructor and the group.

3.2. Example course layout

As an example of the outcomes that can be expected from the course development workshop, we present here in detail the course outline for Topic 4, on “AI in PSE,” as completed by a team of eight participants, headed by the keynote speaker, Artur Schweidtmann. Similar outcomes were achieved by the other three teams. This section details the course learning objective, and syllabus and expands on the planned activities for Week 2 of the course.

3.2.1. Topic 4: Course learning outcomes and schedule

The team working on Topic 4 developed the outline for a master’s level elective course of 4-5 ECTS on “AI for PSE.” Students of the course need to have chemical engineering basics, matrix algebra, calculus, and an introductory course in statistics as prerequisites. It would be advantageous to also have programming experience in Python and have taken an introductory course in optimization. At the end of the course, the student will be able to:

- LO1: Explain the concepts of AI and data analysis
- LO2: Discuss the potential and limitations of different AI methods/tools for given chemical engineering applications
- LO3: Design an AI system to solve a given chemical engineering problem
- LO4: Implement a given or designed AI system using Python
- LO5: Validate an AI model based on data
- LO6: Comprehend state-of-the-art AI research

The course schedule as devised by the team was divided into two approximately equal parts, the first covering the foundations and the second covering applications and project work:

- Week 1: Introduction to Python
- Weeks 2-6: AI foundations
  - Week 2: Data analysis
  - Weeks 3-4: Regression
  - Weeks 5-6: Classification
- Weeks 7-13: Applications of AI in PSE
  - Week 7: Molecular property prediction
  - Week 8: Hybrid modelling
  - Week 9: Demand forecasting
  - …
  - Week 13: Project presentations and assessment

3.2.2. Topic 4: Course plan for Week 2

Team 4 also produced a detailed plan for Week 2, covering data analysis methods. The week’s activity is driven by four learning objectives that indicate that after successfully completing week 2, the student will be able to:

- LO1: Select an appropriate regression method for a given problem
- LO2: Train a regression model on data using common packages
- LO3: Validate a regression model based on data

- LO4: Discuss advantages and disadvantages of common regression tools for a given application

These LOs are achieved by a combination of two phases of self-learning supported by online videos and quiz questions, each followed by in-person sessions involving online quizzes, class discussions, and programming activities in the lab. As shown in Figure 2, the activities have multiple connections to all four learning objectives.

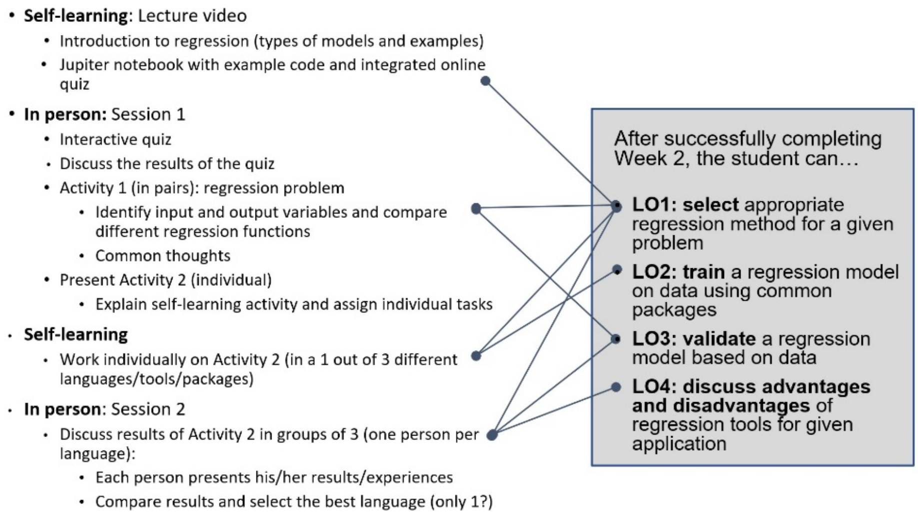

Figure 2. Mapping activities in Week 2 to learning objectives of "AI for PSE".

4. Conclusions

The outcomes of the CAPE Forum 2022 workshop were four master plans, one for each of the topics discussed in the keynote talks (i.e. Carbon-neutral PSE, Sustainable biobased PSE, Energy efficient PSE, and AI for PSE). Each master plan was characterized by a syllabus and a week-by-week schedule, of which most were linked to the learning objectives. In addition, the teams devised exercises, assignments, and projects to be carried out by students of the courses, which address the same learning objectives. The workshop gave a useful course development experience to junior faculty, PhD and EngD students. Following these successful outcomes, a similar educational workshop will be offered as part of the ESCAPE-33 conference program.

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