

# Integrating commercial process simulators into engineering courses

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**Abstract:** The aim of this article is to encourage university lecturers to utilize commercial process simulation software in engineering courses. This article provides examples on four different simulation modules which are implemented in chemical and electrical engineering courses at Oslo and Akershus University College. The students have given positive evaluation on the learning through the simulation exercises and considered the simulation tool easy to use. Together with the exam results the student feedback indicates enhanced learning outcome.

**Keywords:** Commercial simulators, dynamic process simulation, process response, controller tuning.

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## 1. INTRODUCTION

E-labs, including both virtual laboratories and remotely operated laboratories, are widely used in engineering education (Coble et al., 2010, Rutten et al., 2012, Corter et al., 2011, Edgar, 2006). Continuous efforts are made to develop new e-labs, and to improve the quality and accessibility of these. The pan-European Library of Labs project (2013), co-funded by the European Commission, facilitates exchange of access to and experiences of various virtual and remote laboratories with related didactic materials between the participating institutions.

Virtual laboratories are an important addition to the traditional engineering curriculum due to their relevance for the industrial practice, positive learning effects, and time and cost effectiveness (Coble et al., 2010, Martin-Villalba, 2008, Rasteiro, 2009). A review of the learning effects of computer simulations by Rutten et al. (2012) indicates that together with traditional teaching, the simulation exercises facilitate students' conceptual understanding of the theory, improve the ability to predict the experimental results, increase the interest in the course and improve overall learning outcomes. Rutten et al (2012) give many examples on how traditional teaching can be successfully enhanced by utilizing computer simulations.

Important aspects of the arrangement of the virtual laboratories are instructional support prior and during the exercises, and student-centred tasks that facilitate collaborative and active participation (Rutten et al., 2012). Also Corter et al (2011) underline the significance of the social and motivational factors, and the use of effective collaboration tools regardless of the laboratory type. Since the virtual laboratories are only an approximation of reality, the limitations of the simulation models and techniques should be clarified to the students (Coble et al., 2010).

According to Coble et al. (2010) and Corter et al. (2011), the virtual laboratories will continue to play an important role in the engineer education, however the technologies will be

more sophisticated, providing more authentic experiences for the engineering students. One possible way to increase the authenticity of virtual laboratories, is to use industrially relevant commercial simulation tools. Many commercial process simulators, based on high-fidelity non-ideal models of unit operations and process instrumentation with various features of process and instrument failures, provide realistic replicas of the industrial processes and are routinely used to train operators and engineers in companies (Cameron, 2002, Wankat, 2002).

In this paper the integration of a commercial process simulator into chemical and electrical engineering courses at the Oslo and Akershus University College is presented. The didactic framework of the four different simulation modules are explained, and the student and teacher evaluations together with exam results are presented and discussed. Further examples on utilization of the simulation software for operability and safety analysis, and process control courses can be obtained from Komulainen et al. (2012).

## 2. MATERIALS AND METHODS

First, the common features of the four simulation modules are explained, and then, the module specific features explained.

### *2.1 Framework: time, room, group size, software tools, teaching materials and teacher prerequisites*

**Time:** All the simulation modules start with a two hour lecture that includes presentation of the learning goals and the motivation for the simulation exercises, introduction to the dynamic process model, presentation of the simulation tasks and procedures, and a simulator demonstration. All the modules are based on four hours of simulation exercises per student. During this time frame all the students are able to finish the simulation tasks. The first two hours of the simulation session are supervised by the teacher. The students start writing a preliminary simulation report during the simulation session, and are to use approximately two hours

afterwards to finish the report before the workshop. In the two-hour workshop, the students discuss the simulation results in new groups of 4 students. At the end of the workshop the teacher facilitates the summarization of the simulation results and of overall experience on a whiteboard.

**Room and group size:** Each module requires an auditorium with a PC and a whiteboard for the introduction lecture and the workshop, and 4 hours of PC classroom per simulation session. The maximum number of students per simulation session is limited to 8 students since only one teacher/instructor is available, i.e. for a class of 32 students four identical simulation sessions were arranged. The PC classroom should be equipped with PCs for every student and preferably also an instructor station and projector for additional simulation demos.

**Software tools:** The simulation software, D-SPICE, is provided with floating licenses by Kongsberg Oil & Gas Technologies (2011). The software installation to the PC classroom is managed by the IT department of the university college. The licence agreement does not allow the students to download the software to their own laptops. The standard D-SPICE simulation package includes some demo-models that can be used for teaching purposes.

The separation model, given in Fig. 1, represents a small-scale oil and gas production facility that includes two wells with choke valves, a manifold, a three phase separator, a compressor, a heat exchanger, a pump, four control loops, and control and safety valves. The multiphase well streams consist of water, oil and gas components at pressure of 56 bars and temperature of 50°C. The initial state of the model is continuous normal production with well stream flow rates at 3600 kg/h.

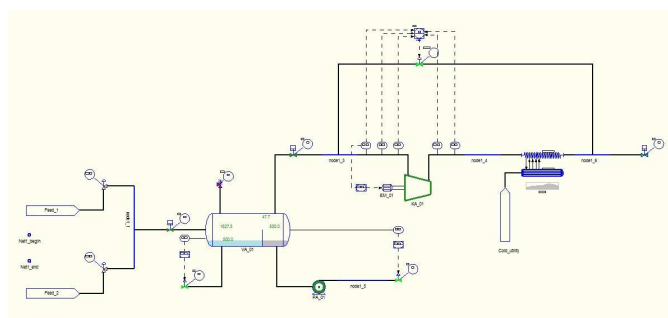


Fig. 1. The small-scale oil and gas processing facility model.

The distillation model, presented in Fig. 2, is configured at the university college based on the laboratory size, Armfield UOP3CC distillation system. The distillation model consists of a feed tank, a pump, a column with 8 sieve-plates, a reboiler, two heat exchangers, a heating coil, two product tanks, and various measurements, valves and control loops. The initial state of the model is continuous ethanol-water distillation with feed flow rate of 16,7 mL/min.

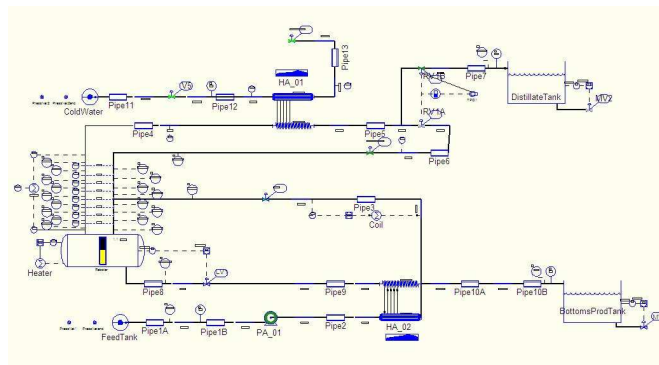


Fig. 2. The distillation model.

**Teaching materials:** The user manual, prepared by the teacher, is specific for the simulation model and the simulation tasks. The user manual includes clear instructions on typical simulation commands; how to load the model, start and pause the simulation, open the relevant variable trends, make different process changes, save the simulation data and how to interpret the results. In practice this decreases level of confusion among the students and increases the amount of relevant questions as well as facilitates mutual comparison of the results during the simulation session. A detailed solutions manual is available for the teacher during the simulation sessions and during the workshop. The solutions manual is made available for the students after the grading of the simulation reports.

**Teacher prerequisites:** The teacher must have experience with dynamic simulation and the commercial process simulation software in order to be able to help the students with various process and software related questions. If the teacher is not familiar with the process simulation software, it could be advisable to invite an instructor from the software vendor. It is important to create a positive learning environment that inspires the students to work together and to discuss the results during the simulation session.

## 2.2. Teaching and learning methods, evaluation

**Teaching methods:** The teacher explains the basics of the simulation tasks and gives a simulation demonstration at the introduction lecture. During the simulation sessions the teacher has an instructor role, helping the students only if the student group cannot find the solution themselves. In the workshop the teacher is a facilitator, setting frames for the group discussions on the simulation results and guiding the final plenary presentation of the results. The teacher gives feedback to the students during the simulation sessions and the workshop, and grades the simulation reports.

**Learning methods:** The simulation tasks are to enhance social interaction in small groups while the main focus is for each student to learn by doing the simulation tasks and reporting in their own pace. Discussions on the simulation results are encouraged during the simulation sessions and during the workshop.

Evaluation: The simulation modules 1, 2 and 3 are evaluated by the students twice, after completed simulation tasks and after completed a laboratory experiment related to modules 2 and 3. A formal multiple-choice questionnaire is used. The learning outcome of the simulation modules is measured using results of the formal final exam.

### 2.3 Goals, contents and prerequisites

The four different simulation modules were implemented based on 4 hours of simulation time per student group. The first and fourth module utilize the small-scale dynamic oil and gas separation process model whereas the second and the third simulation modules are pre-laboratory exercises and utilize the dynamic distillation system model. A summary of the simulation modules are given in Table 1. The further details on the didactic framework of the simulation modules are given in the subsequent chapters.

Table 1. Simulation modules

Module	Process model	Main learning goal
1	Separation	Process response, normal and abnormal operation
2	Distillation	Process response normal operation
3	Distillation	Optimization of a distillation sequence
4	Separation	Tuning and testing of controllers, normal operational disturbances

#### 2.3.1 Module 1

The first module is based on the separation model. The aim is to get familiar with some normal and abnormal operations of a small-scale oil and gas process.

Prerequisites: The students participating the first simulation module are expected to understand the operational principles of a centrifugal pump, a compressor, a three phase separator and control loops based on the theory presented on lectures and the traditional steady-state calculation exercises.

Learning goals: After having completed the simulation module the students shall be able to predict and/or test the dynamic responses in the small scale oil and gas production facility to normal operational changes and process disturbances. The students shall also be able to explain the main economic and environmental aspects of such changes in a small scale oil and gas production facility.

Tasks: The simulation tasks are related normal and abnormal operations of a small scale oil & gas production facility. The dynamic responses in the process equipment together with the economic and environmental indicators are to be collected and analysed. A short overview of the tasks is given in Table 2. The economic indicators are calculated based on the production of oil and gas, and consumption of energy in

the rotating machinery. The environmental indicators are based on pollution, which in this simple model is oil fraction in the produced water, and flaring through the PSV valve of the separator.

Table 2. Simulation tasks, module 1.

Task	Change	Consequence	Response
1.1	Choke valve closure	Production decreases.	Separator, pump, compressor, export valves.
1.2	Oil level setpoint adjustment	No large changes	Separator, pump.
1.3	Oil export valve closure	Export stops	Separator, pump, compressor, export valves
1.4	Incorrect pressure setpoint change	High pressure in the separator	Separator, PSV, pump, compressor, export valves
1.5	Gas export valve closure	Export stops	Separator, PSV, pump, compressor, export valves

#### 2.3.2 Modules 2 and 3

The distillation model is used for the second and third simulation modules, which in practice are obligatory pre-laboratory exercises. The initial condition of the model is a steady state with continuous feed into the column. No measurement noise is added to the model.

Prerequisites: The chemical engineering students are already familiar with the simulation software. Based on theory presented at the lectures and various steady state calculations the students are assumed to be familiar with the operation of a binary distillation column sieve plates, the basic elements of the distillation system (reboiler, column, cooler, valves) and control loops (transmitter, controller and control element).

Learning goals module 2: The students shall be able to use the simulation software, make changes into the input variables (stimulus) and observe changes in the output variables (response). The students shall be able to explain how changes in the manipulated variables of the distillation system affect the dynamic trends of temperature, composition and flow rate in the column. The students shall be able to use the simulation software to find how different changes in the distillation column affect the concentration and flow rate of distillate and bottoms product.

Learning goals module 3: The students shall be able to use the simulation software to test different distillation sequences in order to maximize the ethanol production and to find out the consequences for the total production. Based on the simulations the students shall be able to choose the best

distillation sequence and apply this for the laboratory experiment.

Tasks module2: The aim of the tasks in module 2 is to test the dynamic responses in the temperature and concentrations in the distillation column, and the concentration and flow rate of the distillate towards four different changes one at the time, as given in Table 3. All the simulation scenarios are started from the same initial condition. The results are compared to each other in order determine the most effective actions for the maximization of the ethanol production.

Table 3. Simulation tasks, module 2.

Module	Change	Response column	Response distillate
2.1	Inlet flow rate		
2.2	Heater power		
2.3	Inlet temperature		
2.4	Reflux ratio		

Tasks module3: Module 3 builds on module 2, the task is to design and test two different distillation sequences, both with minimum two changes in the operational parameters and total simulation time of two hours. The best distillation sequence giving maximum ethanol production is to be used in the laboratory experiment afterwards. The students have the possibility to run multiple sequences. In the workshop every group presents one sequence with either successful or unsuccessful results.

### 2.3.3 Module 4

The fourth module consists of controller tuning and testing of PID-controllers on a small scale oil and gas production facility under normal operational disturbances. There are three controllers relevant to this exercise, two level controllers and one pressure controller, all related to the operation of a three phase separator. The initial condition of the simulation model assumes perfect measurements, i.e. there is no measurement noise. The controllers are set on auto and the controllers parameters are in non-optimal “factory settings”.

Prerequisites: The electrical engineering students are assumed to be familiar with the principles of process control and simple PID-controller tuning methods. No previous knowledge of the simulation software or the separation process is required.

Learning goals: The students shall be able to use the simulation software to tune PID controller parameters and to evaluate the controller tuning performance under different kind of process disturbances and equipment failures.

Tasks: The first task is to prepare simulated data for the tuning the three PID controllers. Calculation of the controller

tuning parameters can be based on any suitable method found in the literature. The second task is to apply the controller parameters to the simulation model and to test the feasibility of the tuning in four different scenarios given in Table 4. All the simulation scenarios are to be started from the same initial condition. The tuning methods are to be compared using the calculated overshoot and the time for stabilization for all the control loops. Based on the testing results, the controllers can be re-tuned.

Table 4. Simulation tasks, module 4.

Task	Change	Disturbance
4.1	Level setpoint -10%	None
4.2	Level setpoint +10%	Long sampling interval
4.3	Pressure setpoint +10%	Transmitter noise
4.4	Production increase	Long sampling interval

## 3. RESULTS

The exam results and students’ evaluation of modules 1, 2 and 3 are based on the “Introduction to chemical engineering” course (15 ECTS, fall 2011-spring2012). The teacher evaluation is based on both the chemical engineering course and the “Cybernetics” course (10 ECTS, spring 2012).

### 3.1 Students’ evaluation results

The second year chemistry students have evaluated the simulation modules using two subsequent multiple-choice questionnaires including a total of 62 statements. The background of the second year chemistry students is little or some user experience with mathematical software such as Matlab or Mathematica (85%), and little or no knowledge on process simulation tools (90%).

A summary of the effect simulation exercises have on learning is given in Fig. 3. The majority of the students agreed that simulation exercises are useful for learning and make learning more interesting. Over 90% stated that simulation exercises enhanced their knowledge building and  $\frac{3}{4}$  reported increased learning outcome.

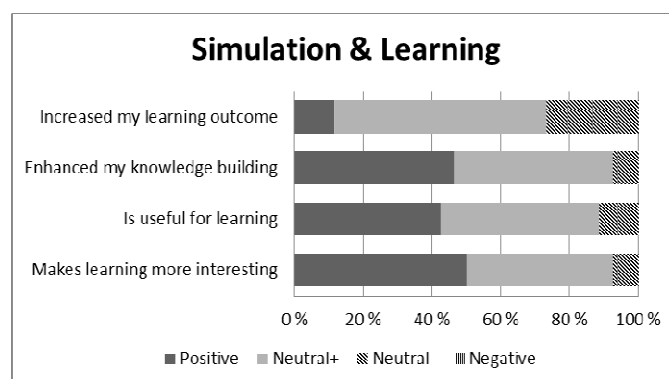


Fig. 3. The effect of the simulation exercises on learning.

Simulation modules 2 and 3 were completed before related distillation laboratory exercise. The students’ evaluation of the simulator utilization is presented in Fig. 4. Almost 80% of

the students agreed that simulation exercises before the distillation laboratory experiment was a good idea and that they gained practical and useful knowledge of distillation through the simulation exercises and the laboratory experiment. Over 90% of the students planned to use the simulation results to choose the distillation sequence parameters based on the simulation module 3 results. Almost 90% of the students used the simulation results in the laboratory.

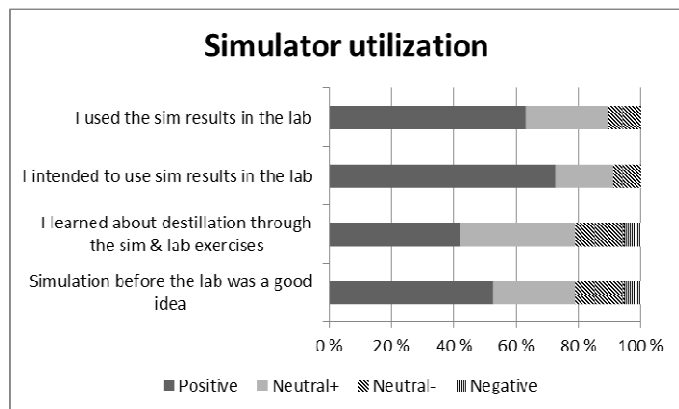


Fig. 4. Utilization of the simulation results for distillation laboratory experiment.

The same simulation tool was used for all the modules in the same PC class room. The students' evaluation on the usability of the simulation tool is given in Fig. 5. Over 60% the students stated that it was relatively easy to learn to use the simulation tool, whereas about 40% of the students had some minor problems. No one reported of major problems with the simulator. About 90% of the students estimated that they could become skilful users of the simulation tool given more time and practical exercises. All the students agreed that the simulation tool is a suitable tool for the chemical engineering course.

The students also suggested using more practical demonstrations on the first introductory lecture, and to use more time with the simulation exercises in order to increase the learning outcome.

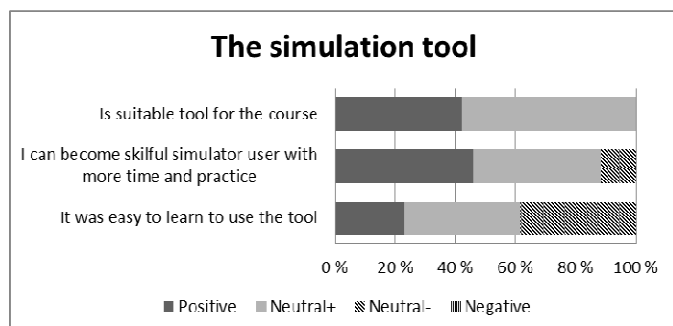


Fig. 5. Evaluation of the simulation tool.

### 3.2 Exam results

The multiple-choice final exam on the introduction to chemical engineering course is divided into three sections, theory (6/20), simulation (4/20) and calculations (10/20) including 20 questions with four alternative answers per question. The exam results for the simulation section, average grade 47%, were better than these for the theory (average grade 43%) and for the calculations (average grade 41%). Also in the re-examination the results for the simulation part were better than these for the theory section and for the calculations (65% as compared to 27% and 47% respectively).

### 3.3 Teacher's evaluation

The simulation modules 1, 2 and 3 are given for the second time in the chemical engineering course and the simulation module 4 for the first time in the cybernetics course. The teacher is alone responsible for the instruction of the simulation modules. She has a couple of years of experience on course instruction using the simulation tool.

The teacher reports a very positive learning environment and enthusiasm in both engineering courses. Even the students with little knowledge on mathematical software were quick to learn the simulation procedures and the students worked effectively in the small groups. Group size up to 10 students was manageable in the simulation sessions. The students were eager to share their experiences in the workshop and the discussions gave an impression of new knowledge and skills acquired through the simulation modules.

The positive effect of the simulation was noticed also in the chemical engineering laboratory and, for the second time, the most successful groups were the ones that had invested a lot of effort on the simulation exercises.

The electrical engineering students participated in only the simulation module 4, and therefore lacked process knowledge, and insight on the normal and abnormal operation of the oil & gas separation system (module 1). This caused longer than expected time consumption on the controller parameter tuning task, and the controller testing (towards measurement noise, set-point changes and process disturbances) had to be omitted. However, the students were eager to complete the tuning tasks and to learn more about the simulation models.

## 4. DISCUSSION

The students were very positive towards the simulation exercises and wished for more time and even more exercises on the simulator. More time spent on various simulation exercises is likely to increase the learning outcome and give positive learning experience for most of the students.

The challenge in the chemical engineering course is to find the right balance between the different topics on heat and mass transfer operations, as well as the balance between theoretical and practical exercises. Through the simulation

exercises students learn how the unit operations in a chemical plant work in practice, which may be a better approach than the traditional equipment design exercises that in the industrial practice are always solved with advanced design-software tools.

The exam results do not quite reflect the learning outcome, as the students tend to get much better grades on the mandatory project work that counts for 30% of the total course grade. The exam form should be revised, preferably to computer based exam including short simulation tasks in order to correspond better to the teaching methods and to the industrial practise.

For the electrical engineering students the simulation module 1 should be taught as a prerequisite before module 4. The first simulation module gives insight into the normal and abnormal operation of a small-scale oil and gas process, something that is necessary for successful implementation of process controller tuning and testing. Based on our experience, simulation module 4 clearly needs to be extended to two four-hour simulation sessions, one with controller tuning using different theoretical algorithms and the other with controller testing. The controller testing should fully utilize the simulators realistic process simulation features, such as different kind of failures in the measurements, failures in the controller configuration and different kinds of process disturbances.

Starting fall 2013, the simulation module 1 will be taught as a part of the dynamic systems course (10 ECTS) that precedes the cybernetics course. The first simulation module will be modified with a few additional tasks on dynamic process responses to normal operational changes in order to better suit the background and interests of electrical engineering students.

## 6. CONCLUSIONS AND FURTHER WORK

The implementation of dynamic process simulation modules to chemical and electrical engineering courses using a commercial simulation tool has been successful.

The students found the utilization of the commercial simulation tool useful and relatively easy to learn as well as reported an increase in their learning outcome. The teacher reported on more motivated students and a collaborative learning environment. According to the teacher, success factors for the utilization of the commercial simulators for educational purposes are experienced instructors/teachers, detailed user and solutions manuals, collaborative tasks in small groups with long enough time for all the students to complete the simulation tasks, and workshops to summarize the experiences and results.

Further efforts will be made to upgrade the software to a newer version, to modify the existing modules and to prepare new modules in collaboration with the simulator vendor and other academic institutions.

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