

LARGE-SCALE TRAINING SIMULATORS FOR INDUSTRY AND ACADEMIA

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ABSTRACT

How should industrial large-scale simulators be used in academia? Which aspects of industrial training can benefit engineering education? This article demonstrates the use of industrial large-scale simulators for educational and training purposes for both academia and industry. The didactic models of the simulator courses are described and the learning results are evaluated for two case examples using the same industrial oil and gas process simulator. The differences and similarities of the didactic models of the courses are explored and the further possibilities for collaboration between academia and industry are outlined.

Keywords: Dynamic process simulation, industrial simulator training, large-scale simulators, engineering education research

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INTRODUCTION

Simulator training in industry

High-fidelity operator training simulators (OTS) including the main process model and the control and safety system, have been used for more than twenty years in the oil and gas industry [1]. The high-fidelity OTS allows realistic, hands-on training of normal operations, startups and shutdowns, plant upsets and emergency situations without compromising the health and safety of the operators, the plant integrity and the surrounding environment [2, 3]. OTS are typically also used for operator training before initial start-up, major plant upgrades, training of procedures, and for regular refresher courses on emergency events [3]. There are numerous benefits related to the simulator utilization, including safety improvements, shorter startups through process and distributed control system testing, enhanced operator performance, trip and incidence avoidance, and knowledge transfer [4-6]. The development of the industrial simulators has traditionally focused on improving the technical quality and the additional functionalities, but during the past decade the educational framework of simulator training and training of team work skills have gained more and more interest [7, 8].

Simulator training in academia

In engineering education, e-labs are widely used as additional learning tools [9-12]. 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 [9, 13, 14]. Rutten et al. [10] indicate that together with traditional teaching, the simulation exercises facilitate students' conceptual understanding of the theory, improve their ability to predict the experimental results, increase their interest in the course and improve overall learning outcomes. Important aspects enhancing learning are student-centered tasks that facilitate collaborative and active participation in groups [10, 11]. The virtual laboratories have become more sophisticated, providing more authentic experiences, for example by utilization of industrially relevant commercial simulation tools [9, 11, 15, 16].

The Norwegian Ministry of Education and Research [17] encourage the education institutions to implement industrially relevant, practical training into the engineering curricula. In the Norwegian petroleum industry all the plants are required to arrange simulator training for the process operators [18], and thus, high-fidelity process simulators are an important tool for process and automation engineers. Since many of the engineering students will be working in the petroleum-related industry after their graduation, industrially relevant simulators with small-scale models have been successfully used at Oslo and Akershus University College [16].

Aims of the article

The aim of this article is to explore the possibilities to use industrial large-scale simulators and assessment methods for engineering education.

In this paper the educational framework of simulator training in the petroleum industry and in academia are presented with two case examples. The case examples are given on a generic large-scale oil and gas process simulator model, using the K-Spice® dynamic process simulation software. The similarities and differences between the industrial and academic simulator training approaches are compared and the possibilities for collaboration are outlined. The didactic model is not software or process model specific, and thus the methods can be transferred to other industrial/academic simulation courses for other chemical processes using other dynamic simulation software.

MATERIALS AND METHODS

First, the simulation software and model are described, and then, the didactic models of the industrial and academic courses are presented in detail.

Software tools

K-Spice® is a high fidelity dynamic process simulation tool, based on over two decades of field testing, engineering studies and successful project deliveries by Kongsberg Oil & Gas Technologies. K-Spice® is used to provide a wide range of services and solutions to the oil and gas industry. These extend from early process design

studies to real-time production management systems, via engineering verification, control system check-out and process training. K-Spice® includes a module library that represents the vast majority of oil and gas unit operations. The equipment modules are all produced with a basis in first principles physics, chemistry and engineering.

Process design of the generic oil and gas production simulator model consists of a three-stage, three-phase separation train. The three-phase flow from the production wells is routed to the High Pressure (HP) Separator or Test Separator, for the initial separation into water, gas and hydrocarbon liquids. The hydrocarbon liquids are further degassed in the Medium Pressure (MP) Separator and then heated before the final degassing is done in the Low Pressure (LP) Separator. Stabilised crude from the Low Pressure separator is routed to an Electrostatic Coalescer for final dewatering prior to export. Water removed in the Coalescer is pumped back to the inlet of the HP Separator.

The associated gas from the Medium Pressure and Low Pressure stages are recompressed to High

Pressure stage pressure, and mixed with gas from the HP and Test separators. This is done prior to the total gas stream being cooled for heavy hydrocarbon removal and then dehydrated by intimate contact with lean Tri Ethylene Glycol (TEG) in a Contactor in order to meet export specifications. The dried gas is compressed and then cooled for delivery into the Gas Export Pipeline. The rich TEG is returned to the Regeneration System.

Produced Water leaving the High Pressure Separator and Test Separator is routed to their respective Hydrocyclones for de-oiling before final degassing in the Degassing Drum and onward pumping to the Water Injection System or disposal to sea. A Test Separator, normally operating at the same pressure as the High Pressure Separator, caters for well testing. To support the process operations a number of utility systems are provided such as cooling medium, sea water and water injection. An overview of the plant is given in Fig. 1. Extensive and detailed documentation of the simulator, process-, automation, and safety system are included in the simulator package.

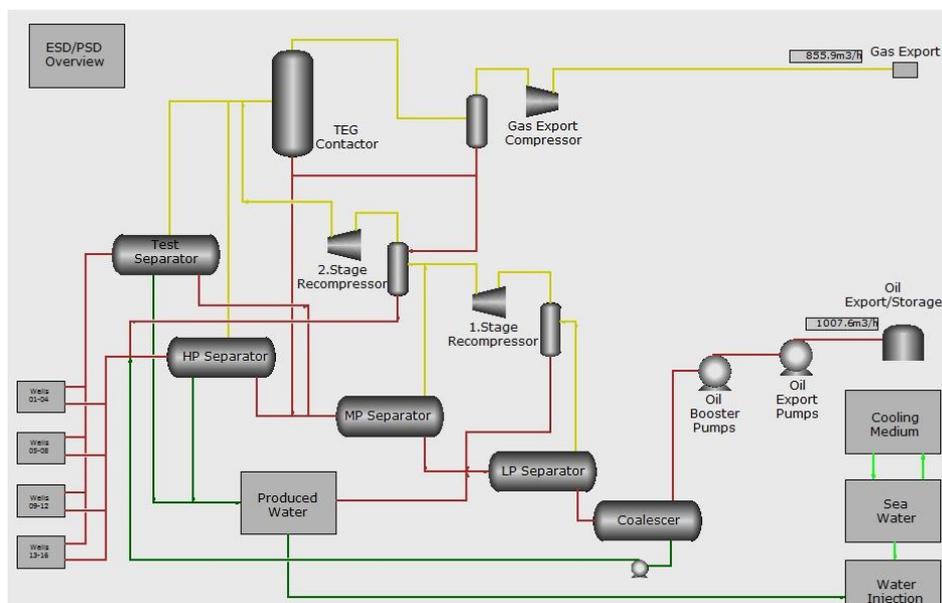


Fig. 1. Overview of the large-scale oil and gas production plant model.

Case1: industrial simulator training

Kongsberg Oil & Gas Technologies provides industrial simulator training for educational and operator training purposes. The generic oil and gas production simulator model is specially designed for teaching and learning different aspects of oil and gas production processes in a safe and informative environment. The simulator is an excellent visual aid to help enhance the learning experience and expand knowledge within process behavior, process equipment, process control and process safety systems.

Training is set up in three levels for varying degrees of difficulty, to target different prior knowledge. The first level is an introduction to oil and gas production processes and includes basic knowledge of process systems, equipment and control together with basic operations. The second level is training on normal process operations, and includes start-up and shut down of process equipment and systems from wells to oil and gas export and utilities. The third level is training on abnormal operations and troubleshooting. This level requires some prior knowledge on normal operations.

Each training level emphasizes practical exercises. The trainees are operating their own simulator

process model and performing predefined exercises. For each level, at the last day of the training course, the trainees are evaluated by executing a set of predefined assessment scenarios. An assessment scenario comprises of triggers, actions and assessments and is combined in a way to evaluate trainee performance on training course content. A computer generated report, giving a score attained by the trainee when assessed, is issued. In addition an instructor observation report for each trainee is issued to supplement the computer generated score. An assessment Scenario Overview is presented in **Fig. 2**.

Framework.

Time: The simulator course length is 4 days at each level. An example on the time allocation is given in **Fig. 2**.

Room and group size: PC-classroom training in small groups of 4 – 10 participants.

Teaching materials: Generic simulator model and workbooks specific for the exercises are used as teaching materials.

Instructor prerequisites: The experienced course instructor has theoretical knowledge on chemical processes and practical skills on process dynamic simulation.

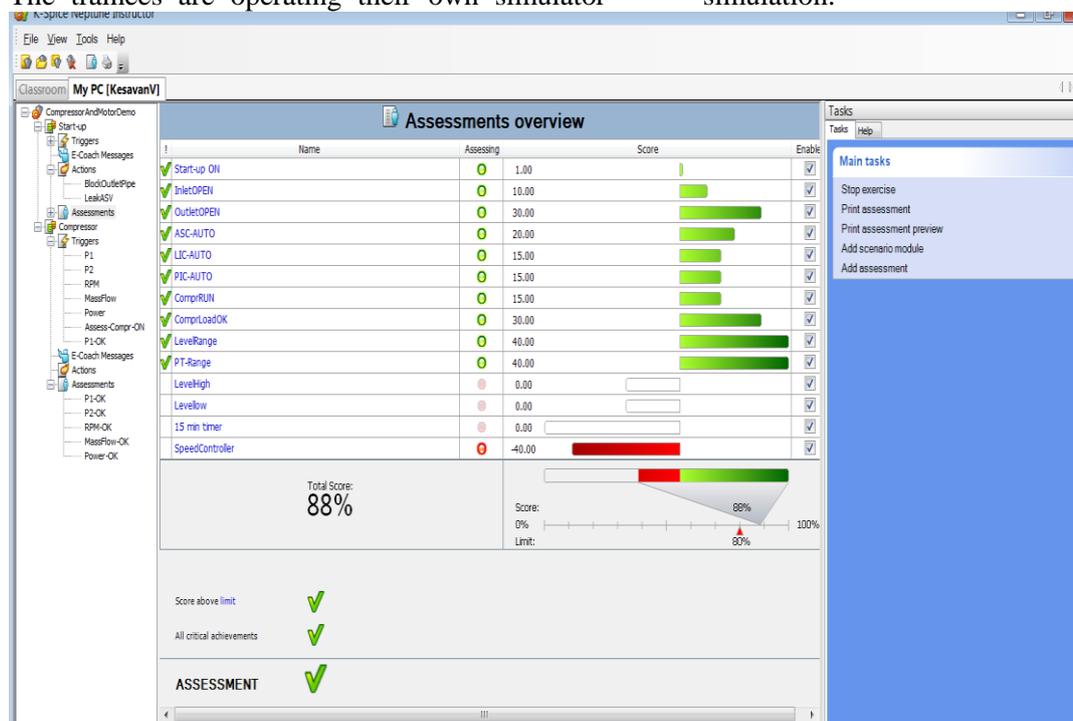


Fig. 2. K-Spice Exercise Manager, Assessment Scenario Overview.

Methods for teaching, learning and evaluation.

Teaching methods: Instructor leads classroom training with theory, practical examples before the simulation session. After the simulation session the instructor leads the debriefing of the practical simulation exercises.

Learning methods: Each of the course participants have a dedicated simulator PC, and operate the simulator model independently. The learning method is “learning by doing” during the simulation session, and by reflection/ peer-learning during the debriefing.

Evaluation: The learning outcome is evaluated using automatic Assessment Scenarios.

Learning goals, prerequisites, tasks.

General comments: No prior knowledge of dynamic simulator models is required. Training courses are suitable for all kinds of professionals that work or aim to work within the oil and gas industry.

Prerequisites: At level three, abnormal process operation and troubleshooting, some process knowledge and operational experience is advisable.

Learning goals: Increase knowledge and confidence within process behaviour and operations.

Examples on typical simulation tasks are given in **Table 2.**

Table 1. Industrial simulation module set-up.

Activity	Description	Time
Briefing	Instructor presents theory and simulation demos	Day 1 -Day 3
Simulation scenarios	Operators work through simulation scenarios	
Debriefing	Instructor gives feedback on completed scenarios	
Exam / assessment	Operators execute assessment scenarios, instructor observes	Day 4
Assessment report	Instructor and operator discusses results, instructor gives final assessment.	
Total time		4 days

Table 2. Examples on typical industrial simulation tasks.

Task A	Compressor Performance. Change: Increase temperature controller setpoint at inlet compressor system Consequence: Cooling medium supply will reduce. Response: Inlet temperature will increase. Hydrocarbon liquids from scrubber will decrease due to increased temperature. Massflow through compressor will increase since more water and heavy hydrocarbons are in gas phase.
Task B	Process Equipment Failure. Change: Machine failure at pump motor. Consequence: Machine will shut down. Response: Pump discharge pressure will reduce due to machine failure, pump is impossible to start and stand-by pump needs to be set in operation.
Task C	Process area start-up. Change: Process shut down (PSD) in gas export area. Consequence: The gas export area will shut down to safety position and all export gas routed to flare. Response: Restart of gas export area after PSD is required

Case2: simulator training for engineering students

In the following framework, teaching and learning methods and the learning goals are presented for the simulation module taught at the Oslo and Akershus University College for courses ELTS2300 Dynamic systems (Automation, 3rd semester, 10 ECTS). A similar simulation module with the same oil and gas process simulator is taught also for course KJTS2100 Introduction to Chemical Engineering (3rd semester, 10 ECTS).

Framework.

Time: The simulation module is implemented using the set-up given in **Table 3.** First, the teacher is presenting the simulator, the dynamic trends and the tasks in a classroom for all the students. Then the students are divided into larger groups that meet for the 4 hour long simulation sessions. The students will work on

familiarization tasks before the simulation scenarios. 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 compare and 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. Total time consumption of the module is 7-10 hours.

Room: The simulation 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 minimum requirement for the PC classroom is one PC per student, and preferably an instructor station that can be connected to a projector for additional simulation demos.

Group size: The students are divided into groups of 10-20 students/session depending on the teaching resources and PC-classroom availability. Optimal group size is about 8 students per session if only one teacher/instructor is available. The students are working in pairs through the simulation tasks, and write the simulation report together.

Teaching materials: The user manual, prepared by the teacher, is specific for the simulation model. 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. A detailed solutions manual, prepared by the teacher, 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.

Instructor 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 that the instructor creates a positive learning environment inspiring the students to work together and to discuss the results during the simulation session.

Table 3. Academic simulation module set-up.

Activity	Description	Time
Introduction lecture/briefing	Teacher introduces simulator, process, dynamic trends, tasks	1-2h
Familiarization software	Work through user manual: typical simulator commands, trend panels	45 min
Familiarization process	Browse through the process: fill in material balance-table	15-30 min
Simulation tasks/scenarios	Dynamic simulation scenarios related to theory, calculations	2-3h
Reporting	Students write report and prepare workshop presentation	2h
Workshop/debriefing	Students present the results	1-2h
Final exam	One exam task on simulation	15 min
Total time		7-10h

Methods for teaching, learning and 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 at their own pace. Discussions on the simulation results are encouraged during the simulation sessions and

during the workshop, i.e. learning from peers and through reflection.

Evaluation: The students evaluate the simulation module as part of the compulsory report using a multiple-choice questionnaire. The learning outcome of the simulation module is measured using results of the formal final exam.

Learning goals, prerequisites, tasks.

The module is motivated by positive effects of good controller tuning in the process industry. Process parameter identification gives a good starting point for controller tuning, and good tuning gives more on-specification production, decreases amount of unplanned partial shut-downs (trips) and disturbances, thus more income for the operating company and less stress for the process operators. A trip is caused by HighHigh (HH) or LowLow (LL) alarm that leads to partial shut-down of the process (PSD) according to the cause&effect chart.

Prerequisites: The student can describe parametrization of simulated step responses for integrating processes and first order processes with time delay. The students are familiar with the basic elements of a control loop: transmitter, controller and control element.

Learning goals: The student gets familiar with the main unit operations and operating principles of typical industrial topsides oil and gas process, and its control and safety systems. The student is able to use an industrial process simulator to run step responses, can classify the process response (integrator, first order process with/without time delay) and calculate the model parameters.

Tasks: A short overview of the tasks is given in **Table 4**.

Table 4. Examples on academic simulation tasks.

Task1	Normal operation, no change Fill in steady-state process values for given 6 points in the process into the Heat & Material Balance
Task2	Level controller in manual mode Change: introduce $\pm 5\%$ change into the level controller output Consequence: Oil level decreases/ increases Response: Integrating process response

	with time delay, level alarm LL/HH causing a trip situation.
Task3	Pressure controller in manual mode Change: introduce $\pm 5\%$ change into the pressure controller output Consequence: Pressure in separator decreases/ increases Response: First order process response without time delay
Task4	Temperature controller in manual mode Change: Introduce $\pm 1\%$ change into the temperature controller output Consequence: Temperature of the export gas decreases/ increases Response: First order process response with time delay

RESULTS

In this section, the evaluations of the industrial and the academic simulator courses are presented.

Case1: Evaluation of the industrial course

In this section results from assessment scenarios after extensive simulator training are presented. A group of oil and gas production operators went through a training program including level 2 and 3 as described in section 2.2. After each level all operators were assessed by a set of 3 assessment scenarios. Average results from the group are presented in **Fig. 3**. Interestingly the results from the level 3 courses have a higher average; the level 3 assessments are more complex than level 2, so the trainees benefitted from the level 2 courses as a prerequisite for level 3.

Feedback from the majority of the operators participating in the training program is that they enjoyed the experience and gained a lot out of it. They found dynamic simulator training motivating, meaningful and enjoyable.

Experience from such training courses shows that assessment of operators is best in combination with computer generated score and instructor evaluation.

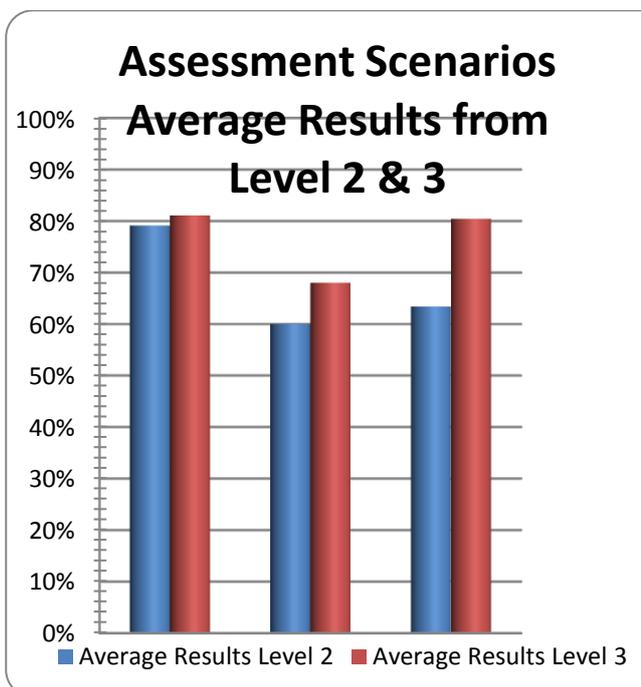


Fig. 3. Average results from assessment scenarios, industrial course, level 2 (blue) and level 3 (red).

Case2: Evaluation of the academic course

A total of 63 second year automation students evaluated the simulation module using an electronic multiple-choice questionnaire including 6 statements. A summary of the answers, given in **Fig. 4**, shows a very positive overall evaluation. All of the students agreed that the simulation exercises are useful for learning, and 97% agreed that simulation exercises increase understanding of process dynamics in fluid systems. The simulation tasks gave practical skills on identification of first order model parameters according to 89% of the students, and gave extra motivation for further studies in control for 80% of the students.

The use of the simulation tool was easy to learn according to 84% of the students, and 92% agree that K-Spice® is a suitable simulation tool for the course in dynamic systems. The average time consumption for the mandatory tasks including reporting was 5 hours.

The formal final exam included 5 sections of which one was about the simulation and model parameter estimation. The average score for the interpretation of the simulation chart was 48%, and the total average score for the exam was 59%.

The exam result is in sharp contrast to the students' and the teacher's positive evaluation of the simulation module. Possible explanations to the low exam score are confusion with the interpretation of the time axis of the simulation chart, something that many students wrote in the exam paper. Another explanation is students did not reach the learning goals because they did not work on the mandatory group tasks individually. However, the issue of interpretation of simulation charts must be addressed next fall semester, possibly with a mid-term test.

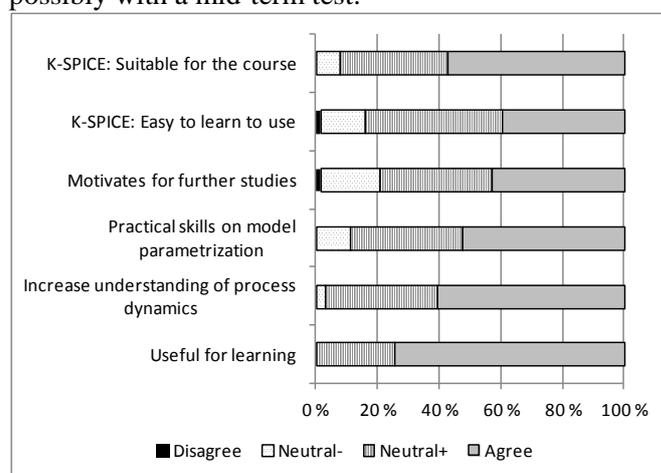


Fig. 4. Students' evaluation of the simulation module, academic course.

DISCUSSION – COMPARISON AND POSSIBILITIES FOR COLLABORATION

Simulator training is partly motivated by governmental requirements: The Petroleum safety authority Norway requires simulator training for all control room operators in the Norwegian petroleum industry, and the guidelines from the Ministry of education and research recommend more practical, industry-relevant content in the engineering education. Simulator training in the industry is motivated by more efficient and safer operation, and by higher revenues. In academia the industrial simulators can provide realistic examples on chemical processes and tools students will use after graduation. Relevant case examples from industry are motivating for the students, and have a great value for the academic courses.

Time spent on simulator training is much longer in the industry than in academia; typically an industrial course lasts from 2 days to 1 week, whereas in academia 1 day per semester is available.

The industrial simulation tools require dedicated simulator rooms or PC-labs; Simulators made available outside of the PC-lab, for example for student-activating classroom tasks during lectures, would be very beneficial for the briefing and debriefing sessions. A simulator-app would also increase the awareness of the simulators and chemical processes, and could be used for training of other working groups and disciplines.

The teaching materials specific for the simulation model and software can be used in academia and industry, but it is necessary to prepare exercise-specific user manuals and solution manuals for each course.

The success of a simulator training course is dependent on inspiring and competent instructors. If the academic staff is not familiar with industrial simulation tools, inviting simulator course instructors from industrial partners / simulator vendor could be a viable solution.

The course participants in the industry typically have a strong practical process background, whereas in academia the students have some theoretical knowledge, but lack practical skills and an overview of unit operations.

The learning goals and contents of the industrial and academic courses are very different. In industry, the purpose of simulator training is to qualify the operators for their daily work, whereas in academia the students learn to use industrial tools and get practical insight into industrial processes. Specification of the skills and knowledge the industry would like the engineering graduates to have is important feedback to the academic institutions.

The teaching methods for simulator training are similar, the structure on briefing/theory – simulation exercises – debriefing/workshop has been effectively used in many other application areas such as aviation, marine and medical simulation.

The learning methods are partly similar, the course participants are supposed to apply their theoretical and/or practical knowledge to solve the

hands-on tasks, and to expand their knowledge during the exercises and the discussions in the debriefing sessions.

The assessment of the learning outcome using traditional exams is common both in academia and industry. In addition the industrial simulator courses rely on subjective evaluation from the instructor. New methods on automatic assessment, such as the K-Spice® Exercise Manager Assessment Scenario Tool, used for the industrial case example in this article, could be beneficial for academic courses with over a hundred participants. Methods to combine the valuable subjective instructor evaluations with automatic assessment could be one collaboration topic.

Further development of effective teaching, learning and assessment methods for process simulator training is an important collaboration area which requires multi-disciplinary research work between industry and academia, including other academic disciplines such as social sciences/pedagogy.

CONCLUSIONS AND FURTHER WORK

This article demonstrates the use of industrial large-scale simulator for academic and industrial simulator courses. The didactic set-up and simulation exercises are not software/ process specific, thus the methods can be transferred to other industrial/academic simulation courses for other chemical processes.

The didactic model for simulator training has provided successful learning results, and the generic oil and gas simulation model has proven to be suitable for academic and industrial courses. The engineering students can greatly benefit from practical case examples using industrial simulation tools, and industrially relevant topics for BSc/MSc/PhD thesis work.

The positive experiences in industry and academia encourage further research and development of didactic/pedagogical model for the simulator courses. Multi-disciplinary collaboration is necessary especially on research and development of the teaching, learning and assessment methods for simulator training.

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