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Looking Ahead: Restructuring Chemical Engineering Undergraduate Curriculum for Optimal Impact of Process Simulation: Student Benefits in Optimization and Sustainability

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ABSTRACT

Proper chemical process simulation knowledge is valuable for senior chemical engineering students to deliver optimal design outcomes and achieve many learning objectives. This study aims to highlight the benefits of continuous improvements and innovations in chemical engineering's undergraduate curriculum. In particular, curriculum restructuring benefits when the simulation course is offered earlier in the curriculum. Most importantly, it elaborates on how this change creates opportunities to help the program attain multiple learning objectives at higher levels. There is a direct modification to the upper-division undergraduate courses (for example, the senior design project course) to incorporate more important in-depth skills, such as optimization and sustainability. The students' summer training experience has also been enhanced to simulate and troubleshoot industrial case studies.

Key words: Chemical engineering undergraduate curriculum, Process simulation, Senior design project

INTRODUCTION

The simulation of chemical processes via professional simulation software is a vital tool needed by chemical engineering graduates. Mastery of such computer skills helps students

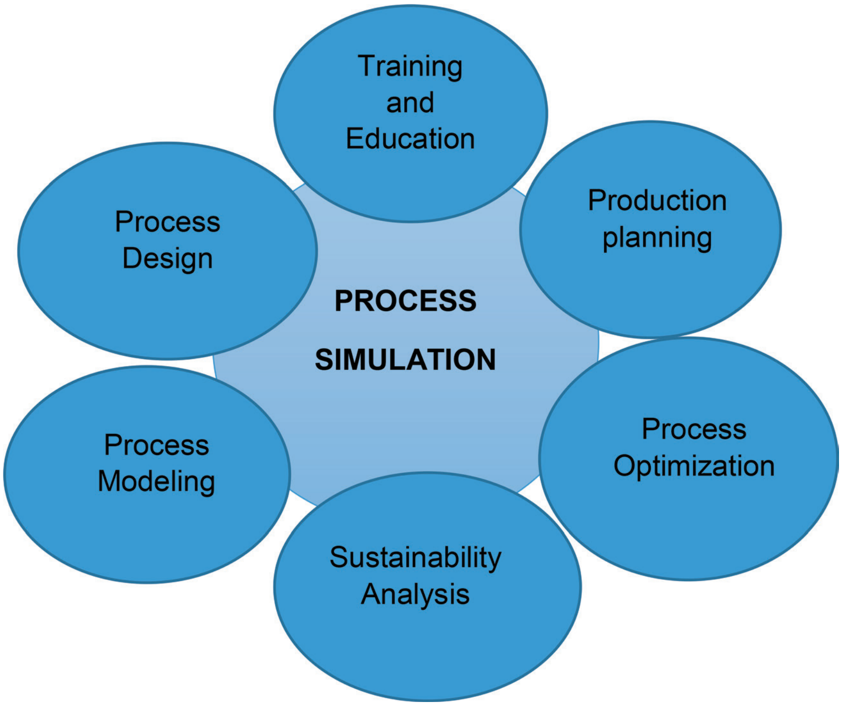

Figure 1. Aspects of process simulation.

function effectively in their senior design projects, industrial training internships, and post-graduation studies. Chemical process simulation, also known as process flowsheeting, represents chemical processes using embedded material and energy conservation, thermodynamics, transport phenomena, and design equations that are solved simultaneously using built-in models to predict process performance (R. L. Motard 1975). Thus, process simulation plays an important role in chemical system design and optimization (A. W. Westerberg 1979). Aspen Plus, Aspen HYSYS, ChemCAD, and PRO/II are examples of commercial simulation packages (Aspentech 2017).

The role of process simulation in addressing chemical systems is extensive, as shown in Figure 1. Process simulation helps in process operation and production planning, process optimization, training and education, sustainability analyses, and decision-making studies.

(Ghasem 2016) showed that the simulator-based learning approach enhanced students' technical knowledge. He highlighted that learning through simulators also favors the industrial community and stakeholders. (KlemeŠ et al. 2013) indicated that process design, modeling, simulation, synthesis, integration, optimization, and dynamics are examples of essential subjects for students to attain the skills necessary for solving complex engineering problems. This recommendation was reached after reviewing the standards, such as the EUR-ACE framework standards. Some of our previously published works presented the simulation-optimization frameworks. For example, (Al-Sobhi and Elkamel 2015) developed a strategy via simulation to optimize an enterprise-wide natural gas processing network. Al-Sobhi et al. extended the simulation-optimization framework for the optimal selection of economic and environmental sustainability pathways (Al-Sobhi, Shaik, et al. 2018) (Al-Sobhi, Elkamel, et al. 2018). These works focused on presenting a sustainable design considered an emerging research area by process system engineering (PSE) society. It broadens the investment decision from focusing on profitability analysis (Al-Sobhi and AlNouss 2018) to consider other aspects such as environmental impact and safety (AlNouss, Ibrahim, and Al-Sobhi 2018). Sustainability has already been incorporated into engineering education at many universities worldwide (Glassey and Haile 2012) (Murphy et al. 2009). Recently, (Borreguero et al. 2019) presented a study towards a nexus of knowledge applied to specific cases in the chemical industry using simulators. They concluded that using simulation packages such as Aspen HYSYS or Aspen Plus is appropriate for process optimization, energy integration, and analysis of environmental issues.

The research questions that guide this study are:

- How does earlier exposure to simulation skills help senior students achieve higher levels of learning?
- How does such modification motivate senior students to deliver more sustainable senior project designs?

METHODOLOGY

This study aims to discuss the benefits of modifying the curriculum by moving the computer-aided course (Computer Methods in Chemical Engineering) to the junior year instead of the senior year. The course switches a general university course in place, which assures not sacrificing the prior knowledge in any other core course. It is designed to equip students with the needed skills to powerfully use different software to simulate, solve, and manage chemical processes. The software list includes commercial simulation packages such as ASPEN HYSYS, ASPEN PLUS, and HTRI software. This course covers the following skills:

- Chemical process flowsheet construction
- Unit operation modeling and logical operations
- Thermodynamic fluid packages selection

- Case studies and sensitivity analysis tools for process optimization
- Simulation results validation and reconciliation

PRELIMINARY RESULTS

Preliminary feedback and insights were collected via questionnaires answered by multiple stakeholders such as senior students (2019–2020), senior design project (SDP) supervisors, and the practical summer training course coordinators (Summer 2018, Summer 2019). Summer training is practical training where the students have the opportunity to spend eight weeks in hosting companies for training (Summer of year 3). The SDP is a senior course in the Fall and Spring semesters of year 4 in the program. The SDP course syllabus is revised to reflect the added value of the proposed curriculum changes. These changes are being piloted in the 2020-2021 academic year and analyzed further. Responses to the questionnaire sets were received from five SDP course instructors/supervisors, two summer training faculty supervisors, and 39 senior students, as shown in Table 1.

Although the practical training supervisors agree that even when the practical training activities are not associated with process simulation, the simulation pre-knowledge would help students complete the training tasks effectively and enrich their summer training experience. Furthermore, all SDP course instructors strongly agreed that students with prior simulation experience could perform more effectively in tasks associated with their senior design projects. The students represent the clients of the teaching-learning process. The input received from senior students was very encouraging. There was general agreement that the modification was helpful and supportive. Almost 90% of the respondents indicated either "agree" or "strongly agree" on most of the questionnaire statements.

The curriculum modification contributes significantly to the SDP course syllabus by incorporating more sustainability analyses and optimization, as shown in Figure 2. The modified SDP course syllabus focuses on chemical plant energy optimization and the corresponding economic, environmental, and social impacts. The simulation tools are used to determine energy consumption targets and saving potentials by applying heat integration techniques.

To be specific, the new topics for sustainability analyses and energy management and optimization may include

- Identification of energy targets and greenhouse gas (GHG) reduction early in the design process
- Development of effective process modifications and adjustments to maximize energy-saving and integration opportunities
- Optimization of energy savings with alternative design options

Table 1. Primary stakeholders feedback.

A. Summer training superviors (2 respondents)							
Statement	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Disagree + Strongly Disagree**	**Agree + Strongly Agree**
A.1. Students need to have good knowledge of computer methods in ChE before their training	0%	50%	0%	50%	0%	50%	50%
A.2. Students with prior knowledge in computer methods in ChE can perform more effectively in their tasks	0%	0%	0%	100%	0%	0%	100%
A.3. If needed, students can learn computer methods in ChE during their training to perform effectively in their tasks at the same level as those who had prior knowledge in this topic	0%	50%	50%	0%	0%	50%	0%
B. SOP instructors (5 respondents)							
Statement	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Disagree + Strongly Disagree**	**Agree + Strongly Agree**
B.1. The tasks associated with the SDP project need knowledge in computer methods in chemical engineering, e.g., process simulation packages.	0%	0%	0%	0%	100%	0%	100%
B.2. Students need to have good knowledge of computer methods in ChE prior to their senior year	0%	0%	20%	20%	60%	0%	80%
B.3. Students with prior knowledge in computer methods in ChE can perform more effectively in their tasks	0%	0%	0%	0%	100%	0%	100%
B.4. If needed, students can learn computer methods in ChE during their SDP course to perform effectively in their tasks at the same level as those who had prior knowledge in this topic.	40%	20%	0%	40%	0%	60%	40%
C. Senior Students (39 respondents)							
Statement	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Disagree + Strongly Disagree**	**Agree + Strongly Agree**
C.1. It helped in performing well in senior level courses specially SDP	5%	0%	5%	21%	69%	5%	90%
C.2. Taking it prior to senior year would help in performing better in senior level courses specially SDP	5%	0%	5%	15%	74%	5%	90%
C.3. Summer training would be better if I took computer methods course before summer training	15.4%	15.4%	26%	8%	36%	31%	44%
C.4. It contributed to better understanding of checmial engineering principles / concepts	5%	0%	8%	23%	64%	5%	87%

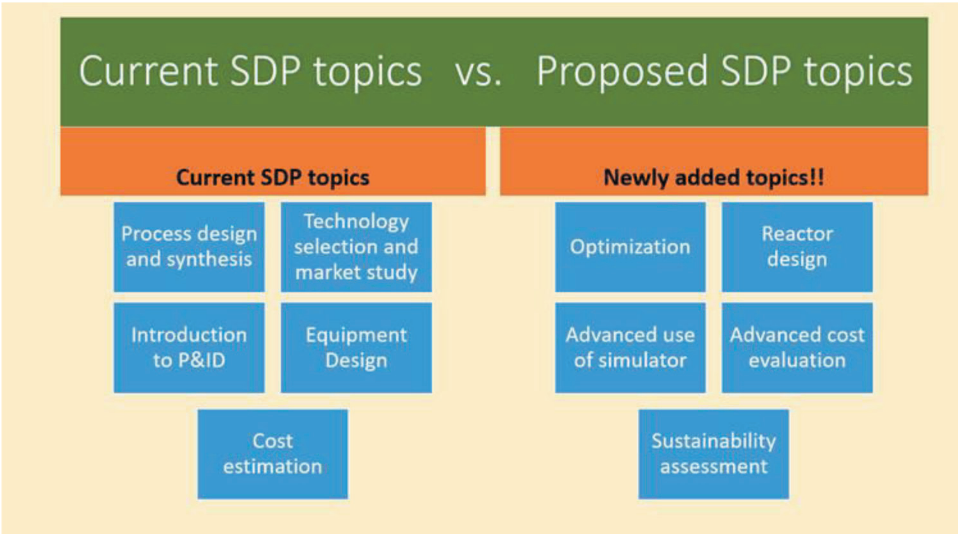

Figure 2. Current vs. proposed senior design project course topics.

CONCLUSIONS AND NEXT STEPS

The curriculum modification with earlier exposure to simulation skills was beneficial to enrich the educational experience of senior chemical engineering students. It comprehensively improved the attainment of the undergraduate program learning outcomes. It also positively impacted program milestones and activities, including the summer training, the senior design project, and technical elective courses. The direct impact focused on a notable outcome was incorporating more optimization and sustainability topics, tasks, and assessments in the senior design project syllabus. Furthermore, the students learned better because they can investigate many design aspects with simulation skills. Even though the current analysis shows indirect measures as students and instructors perceive, we will directly assess the design projects over the next few years and compare them with delivered designs in previous years for the next steps. We will also collect and analyze the industrial stakeholder's input to reflect upon the curriculum modification's contributions.

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