Computer-aided Process Simulation Modules in ChE Education

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Abstract

This paper describes the development of new process simulation modules and associated teaching materials that is integrated within the capstone design course. The process simulation package HYSYS is used to develop these modules. The main advantage of using a process simulator in promoting the systems approach is its powerful interactive feature that allows students to specify and modify, in real-time, physical properties such as pressure and temperature, chemical properties, and other relevant process parameters of a system being studied. Subsequently, the students can observe the resulting changes not only on the individual unit operations but more importantly, on the overall system behavior as well as the operating economics, which really are the actual aspects emphasized by the systems approach. Likewise, by using a process simulator, the students can reproduce controlled 'misbehavior' of the system and in so doing, be able to study, understand, and appreciate the effects and impacts of the various process parameters on each and every component of the system.

The new modules and teaching material proved to actively engage students' participation and have been integrated horizontally through time so that the principles each set of modules stresses on are easily mastered from week to week. The modules were developed in such a way that they proceed from simple to complex applications. The modules have been integrated vertically so that they can reinforce the subject matter learned by the students in the lecture component of the capstone design course. Vertical integration has been achieved by developing modules that are directly related to the topics the students are currently taking in a particular week.

Keywords

1. Introduction

The chemical engineering curriculum at the Petroleum Institute (PI) has undergone continuous changes to provide students with a rigorous education in the fundamentals of chemical engineering science. The curriculum also aims at giving students specific training in applications of chemical engineering in the oil and gas industries. The current chemical engineering curriculum at the PI represents well the general attributes of any reputable curriculum of a well-known university around the globe. As highlighted by the Council for Chemical Research (Armstrong, 2006), these attributes include: molecular transformations, multi-scale descriptors, and a systems approach. However in the current PI chemical engineering curriculum, the systems component seems to be not addressed well enough.

The motivation of the present work was to focus on the systems component and enhance the training of chemical engineering students at the PI in the area of Process Systems Engineering. The project was also aimed at expanding the learning of students in the laboratory of the capstone design course (CHEG490 lab). New computer simulation labs and open-ended case studies were integrated within the course. Over 50 students a year are benefiting from this improvement. Students had hands-on-experience with state of the art simulation software (i.e. Aspen HYSYS) and were able to conduct more true-to-life engineering simulations of more complex chemical engineering processes. Moreover, working on these real-life industrial case studies enabled undergraduate senior students to understand the importance of the systems approach as an improving educational concept to be adopted in the undergraduate curriculum and to meet ABET requirements. This in addition to the requirement that graduating students must possess the ability to effectively use computational and process simulation tools necessary for chemical engineering practice.

Process simulators, such as Aspen HYSYS, are being used extensively in senior level chemical engineering design courses, and are becoming more prevalent in lower level courses (i.e. 200- and 300-level courses). Aspen HYSYS is one of a powerful engineering simulation tool, has been uniquely created with respect to the program architecture, interface design, engineering capabilities, and interactive operation. It is widely used in universities and colleges in introductory and advanced courses especially in chemical engineering. In industry, the software is used in research, development, modeling and design. This report describes the development of new process simulation modules and associated teaching materials that is integrated within the capstone design course. The process simulation package Aspen HYSYS is used to develop these modules. In order to achieve the aims set forth so far, this project was focused on the following objectives:

1. Improve the undergraduate chemical engineering students' learning in the process systems area,
2. Prepare students to accept and use computational tools to solve more realistic chemical engineering problems,
3. Develop the necessary skills for the students to be able to easily apply computational tools,
4. Demonstrate students' ability to learn appropriate software packages, and
5. Enhance students' proficiency in evaluating and interpreting the results obtained.

2. Our Approach for Course Enhancement

Up to last year, the lab component of the chemical engineering capstone design course was under the sole responsibility of a laboratory engineer. Usually the students learn about the Aspen HYSYS process simulator but do not go through well-structured teaching modules and open-ended case studies. There was no formal assessment of the teaching efficacy of the lab component of the course. Therefore, our project is an innovative concept. Making use of the developments from this project, the chemical engineering students now have a set of effective educational computer simulation lab modules that helps them to learn the tools of process simulation and systems engineering. Furthermore, when students got acquainted to the systems thinking, they showed stronger motivation to learn other computational tools and to apply them to follow-up courses, such as gas processing, petroleum refining, and separation processes.

In order to meet the above stated objectives, we proposed the development of new process simulation modules and associated teaching materials that will be integrated within the capstone design course. We focused on the process simulation package Aspen HYSYS. Other commercial process simulation software packages today include CHEMCAD, PRO/II with PROVISION, and SuperPro Designer. According to Seider et al. (2004), it is relatively straightforward to switch from the use of one simulator to another once the principles of process simulation have been understood. Our choice of Aspen HYSYS was based mainly on the existing faculty and lab technicians' expertise within the PI and the software licensing agreement that meets the department's budget.

The main advantage of using a process simulator in promoting the systems approach is its powerful interactive feature that allows students to specify and modify, in real-time, physical properties such as pressure and temperature, chemical properties, and other relevant process parameters of a system being studied. Subsequently, the students can observe the resulting changes not only on the individual unit operations but more importantly, on the overall system behavior as well as the operating economics, which really are the actual aspects emphasised by the systems approach. Likewise, by using a process simulator, the students can reproduce controlled 'misbehaviour' of the system (Mah and Himmelblau, 1996). In so doing, students will be able to study, understand, and appreciate the effects and impacts of the various process parameters on each and every component of the system. Process simulators have also proven to be an effective teaching tool to demonstrate a multitude of chemical engineering concepts primarily the fundamental core principles of the field. These core fundamentals include: material and energy balances, thermodynamics (in particular, physical and thermodynamic property analysis, estimation, and regression), reactor design, transport phenomena (heat and mass transfer), multi-component separations, and process flowsheeting (CACHE, 2004 and Edgar, 2006). In delivering these modules, we followed an approach that was successfully utilized for the teaching of similar modules (Khor et al., 2008). The teaching and learning activities took the form of two three-hour computer laboratory modules, each structured as follows. In the first hour, the course instructor provides formal instruction on using the simulator, with the students following along on their individual personal computer terminals. Within this setting, the instructor functions both as a facilitator and as a personal tutor by moving around and interacting openly with the students on a one-on-one or small group basis. In instances where there are common problems and misunderstandings faced by the students, the instructor can switch to delivering a mini lecture to address the issue. Edgar et al. (2006) have highlighted the success of such an integrated lecture. In the subsequent second hour, the instructor supervises hands-on practice for the students and

educates them in the difference between the incorrect uses of the software as opposed to an incorrect understanding in formulating solutions to a problem. The final third hour is an optional self-regulated free practice for the students, in which they are encouraged to help and discuss with each other, and in so doing, achieve independent learning-by-doing, a suggestion reported with considerable success by Wankat (2002).

3. Modules Development

The new modules and teaching material proved to have actively engaged students' participation and were integrated horizontally through time so that the principles each set of modules stresses on are easily mastered from week to week. The modules were developed in such a way that they proceed from simple to complex applications. The modules were also integrated vertically so that they can reinforce the subject matter learned by the students in the lecture component of the capstone design course. Vertical integration was achieved by developing modules directly related to the topics the students were currently taking in a particular week. This enabled the students to apply the materials they were currently learning to more realistic case studies of the lab modules. The developed modules and learning outcomes are summarized in Table 1. A brief description of each module is provided below. For the interested readers, the process flowsheet and layout as well as the design parameters of each of the studied unit operations can be obtained by contacting Salah Abu Yahya at sabuyahya@pi.ac.ae.

3.1 Module 1: Introduction to Process Flowsheet Simulation

This module begins by starting Aspen HYSYS and how to select the right components and fluid package for simulation purposes. Knowing how to start HYSYS and get familiar with its desktop is very important in this module. The second part is about how to enter and re-enter the simulation environment, and get familiar with simulation flowsheet. In this module, users are informed some important features of Aspen HYSYS. The last part is dealing with how to add and specify material streams for simulation and run the flowsheet. Variables specification is one of the important steps that users need to understand when dealing with Aspen HYSYS.

3.2 Module 2: Rotating Equipment (Pumps, Compressors and Expanders)

This module begins with a problem to find the rotating equipment (e.g. pumps, compressors and expanders) outlet temperature when given the pump, compressor or expander efficiency. The user operates a rotating equipment operation in Aspen HYSYS to model the pumping, compressing or expanding process. The user will also determine the pump, compressor or expander outlet temperature when given compressor power is given or vice versa. This module on the other hand shows the several methods for the centrifugal compressor or expander to solve, depending on what information has been specified, and whether or not you are using the compressor's characteristic curves. During the introduced problems in this module, the user defines a new component in Aspen HYSYS using a hypothetical component option.

3.3 Module 3: Heat Transfer Equipment

This module begins with a problem to find the flowrate of the cold stream passing through the heat exchanger at the given stream conditions. In this module Aspen HYSYS's shell and tube heat exchanger will be used to model the process. The heat exchanger performs two-sided energy and material balance calculations. The heat exchanger is very flexible, and can solve for temperatures, pressures, heat flows (including heat loss and heat leak), material streams flows, or UA. In Aspen HYSYS, you can choose the Heat Exchanger Model for your analysis. Your choices include an End Point analysis design model, an ideal (Ft = 1) counter-current weighted designed model, a steady state rating method, and a dynamic rating method for use in dynamic simulations. The dynamic rating method is available as either a Basic or Detailed model, and can also be used in Steady State mode for Heat Exchanger rating.

3.4 Module 4: Separation Columns

This module begins with definition of the features of four types of separation columns which are; flash separator, 3-phase separator, tank separator and component splitter. In steady state mode, the Separator divides the vessel contents into its constituent vapor and liquid phases. The vapor and liquid in the vessel are allowed to reach equilibrium, before they are separated. The separator has the ability to back-calculate results. In addition to the standard application (completely defined feed stream(s) being separated at the vessel pressure and enthalpy), the separator can also use a known product composition to determine the composition(s) of the other product stream(s), and by a balance the feed composition. A solved problem is introduced to find the flowrate and the composition of

Table 1: Developed modules and learning outcomes

1. Introduction to Process Flowsheet Simulation:	2. Pumps, Compressors and Expanders:
After completion of this module, students should be able to: a) open the Aspen HYSYS software and initialize a new flow sheet. b) appropriately select components and thermodynamic properties package (Fluid package) c) enter and re-enter the simulation environment, and get familiar with simulation flowsheet d) add and specify known streams and unit compositions and conditions. e) run the simulation program. f) interpret the results.	**After completion of this module, students should be able to:** a) define the function of pumps, compressors and expanders. b) add pump, compressor and expander in Aspen HYSYS. c) how to determine the pump, compressor or expander outlet temperature when given compressor power is given or vice versa. d) use the characteristic curve of centrifugal compressor and expander to solve for them. e) define a new component in Aspen HYSYS using a hypothetical component option.
3. Heat Transfer Equipment:	**4. Separation Operations:**

After completion of this module, students should be able to:
a) define shell and tube heat exchanger (configuration, streams) in Aspen HYSYS
b) solve for unknown stream temperature, heat flow (including heat loss and heat leak), material stream flow (hot and cold side) and UA value.
c) introduce three types of heat exchanger models for analysis which are: End point model, weighted model and rating model.
d) choose the appropriate model to be used depending on co-current flow, counter current flow and the correction factor Ft.
	After completion of this module, students should be able to:
	a) define four types of separation columns which are:
	  • Flash separator.
	  • 3-phase separator
	  • Tank separator
	  • Component splitter
	b) clarify the function of each separator as well as its configuration in Aspen HYSYS
	c) figure out the importance of inlet feed pressure and pressure drop inside the flash separator on the results obtained.

5. Absorber:	**6. Distillation Columns:**
After completion of this module, students shold be able to: a) define the physical concept of the absorption process and add the absorption column on the main flow sheet in HYSYS. b) distinguish between three templates of absorbers: absorber, re-boiled absorber and refluxed absorber. c) introduce the concept of sub-flowsheet as the absorption is modeled in HYSYS as column. d) simulate the gas absorption process in packed column and estimate the conditions and compositions of the column streams. c) how to use the "Utilities/ Tray Sizing" option in HYSYS to size the absorber (column design parameter, diameter, height for a packed column, and number of trays for a tray column).	**After completion of this module, students should be able to:** a) define the physical concept of the distillation process and add the distillation column on the main flow sheet in HYSYS. e) introduce the concept of sub-flowsheet as the distillation is modeled in HYSYS as column. b) simulate distillation columns using rigorous methods (perform mass and energy balances, estimating condenser and reboiler duties using different specifications from the monitor page in HYSYS) c) perform column design and sizing for packed bed and tray columns using the "Utilities/ Tray Sizing" option in HYSYS. d) simulate short cut distillation to estimate the actual reflux ratio.
7. Logical operations ADJUST & SET:	**8. Reactors I:**

After completion of this module, students should be able to:
a) introduce five types of logical operations which are:
  • SET
  • ADJUST
  • RECYCLE
  • BALANCE
  • SPREAD SHEET
b) be familiar with the specific use and of each logical operation, its features and its importance in the flow sheet.
c) simulate the flash separator process and use the ADJUST block and be able to change its parameter (adjusted/target variable, target value, step size).
d) simulate the conversion reaction ($CO+3H_2 \rightarrow CH_4+H_2O$) in HYSYS and use the SET block in the simulation and be able to change its parameters (target object, target variable and source object).
	After completion of this module, students should be able to:
	a) define the five reactors which share common property views:
	  1. CSTR 2. GIBBS 3. EQUILIBRIUM
	  4. CONVERSION 5. Plug Flow (PFR)
	b) define the reactions inside the Basis Manager, group them into a set and then attach the set to your reactor.
	c) create reactions in the Reaction Package in the Main Flowsheet, group them into a set and attach the set to the reactor.
	d) create reactions and reaction sets in the Basis Environment and make changes in the Main Environment's Reaction Package.
	e) simulate isothermal and adiabatic conversion, equilibrium, and CSTR reactors in HYSYS .
	f) perform a case study on the effect of temperature, pressure, and flow rate on conversion and size the reactors.
	g) provide the binary coefficient for UNIQUAC fluid package in HYSYS.

9. Reactors II:	**10. Case Studies:**
After completion of this module, students should be able to: a) clarify the concept of the PFR reactor, its features, its configuration and its difference from the other four types of reactors that discussed in module 8. b) simulate isothermal and adiabatic PFR reactor in HYSYS. c) perform a case study on the effect of temperature, pressure, and flow rate on conversion. d) plot the composition and temperature profiles along a PFR reactor. How to size the PFR reactor depends on pressure drop through the reactor which could be specified either by the user or using Ergun equation built in HYSYS.	**Case I:** Synthesis Gas Productions **After completion of this case study, students should be able to:** a) perform a complete process flowsheet simulation with multiple unit operations including reactors, heat exchangers, coolers, pumps and combustors. b) use the **SPREAD SHEET** block in HYSYS and apply it to the production of the synthesis gas process to control the ratio of $H_2:N_2$. c) apply the SET, Adjust and recycle blocks on the process. **Case II:** Methanol Process **After completion of this case study, students should be able to:** a) simulate a complete process with multiple unit operations including reactors, heat exchangers, coolers, pumps and flash drums. b) be proficient in the use of the RECYCLE block in HYSYS. c) use the recycle block tabs in HYSYS (tolerance page, acceleration delay, and nested and simultaneous recycles).

the liquid and vapor outlet streams of the flash separator (the first type). A Flash Separator is performed to determine the product conditions and phases. The pressure at which the flash is performed is the lowest feed pressure minus the pressure drop across the vessel. The enthalpy is the combined feed enthalpy plus or minus the duty.

3.5 Module 5: Absorbers
This module begins with introducing the physical concept of the absorption process. As long as the gas absorption process is modeled in Aspen HYSYS as a column, the sub flowsheet in Aspen HYSYS will be explained since the column is a special type of sub-flowsheet in Aspen HYSYS. A sub-flowsheet contains equipment and streams, and exchanges information with the parent flowsheet through the connected internal and external streams. This module also introduces the use of Aspen HYSYS to model a continuous gas absorption process in a packed column. The only unit operation contained in the absorber is the Tray Section, whereas the outlet streams differ depends on the type of the absorber (simple absorber (basic9, refluxed absorber and reboiled absorber) which in turn affect the required specifications for the absorber. In the last part of this module a solved problem shows the use of Aspen HYSYS to model a continuous simple gas absorption process in a packed column. The conditions and composition of the column feed stream, as well as the operating pressure, define the resulting converged solution. The converged solution includes the conditions and composition of the vapor and liquid product streams as well as the dimension of the absorption column e.g. section diameter, section height.

3.6 Module 6: Distillation
This module begins with introducing the physical concept of the distillation process. As long as the gas absorption process is modeled in Aspen HYSYS as a column, the sub flowsheet in Aspen HYSYS will be explained since the column is a special type of sub-flowsheet in Aspen HYSYS. Different required specifications that needed for convergence of the distillation column are explained in details. Sizing of the distillation columns using the tray sizing utility introduced in this module. In the last part of this module, a solved problem shows how to use the shortcut method to estimate the Rmin–as the rigorous method needs this value to simulate the column.

3.7 Module 7: Logical Operations
This module introduces five types of logical operations found in Aspen HYSYS. The specific use for each logical operation, its features and its importance in the flow sheet were discussed in details. Solved problems include some of the mentioned logical operations were introduced as well.

3.8 Module 8: Reactors 1
With the exception of the plug flow reactor (PFR), all of the reactor operations discussed in this module share the same basic property view. The primary differences are the functions of the reaction type (conversion, kinetic, equilibrium, and heterogeneous catalytic or simple rate) associated with each reactor. As opposed to a separator or general reactor with an attached reaction set, specific reactor operations may only support one particular reaction type. This module focuses on the following points:
•   Define the reactions inside the Basis Manager, group them into a set and then attach the set to your reactor.
•   Create reactions in the Reaction Package in the Main Flowsheet, group them into a set and attach the set to the reactor.
•   Create reactions and reaction sets in the Basis Environment and make changes in the Main Environment's Reaction Package.
While simulating a flow sheet involves reactor unit operation, providing binary coefficients for UNIQUAC fluid package in Aspen HYSYS will be discussed by the way in this module as well as creating different case studies showing the effect of different parameters on another one. Isothermal and adiabatic mode for the reactors discussed in this module were presented as well as its effect on the put let stream temperature. Regarding to the equilibrium reactors, the equilibrium constant required to run this type of reactor will be either estimated through built in empirical equations inside Aspen HYSYS or by user specified.

3.9 Module 9: Reactors 2
As long as the PFR reactor has different features than the reactor types introduced in Module 8, it generally consists of a bank of cylindrical pipes or tubes. The flow field is modeled as plug flow, implying that:
•   The stream is radially isotropic (without mass or energy gradients).
•   The axial mixing is negligible.

PFR means:
• As the reactants flow the length of the reactor, they are continually consumed, hence, there will be an axial variation in concentration.
• Since reaction rate is a function of concentration, the reaction rate will also vary axially (except for zero-order reactions).
The temperature profile, pressure profile, species concentration profile, and overall concentration profile will be introduced and discussed in this module in details. Isothermal and adiabatic mode for the reactors discussed in this module were presented as well as its effect on the put let stream temperature. Sizing of the PFR reactor will also be introduced in this module depends on pressure drop through the reactor which could be specified either by the user or using Ergun equation built in BHYSYS.

3.10 Module 10: Case Study I
In this module, the Synthesis Gas Productions case study was introduced and solved completely

3.11 Module 11: Case Study II
In this module, the Methanol Process case study was introduced and solved completely

4. Modules Assessment and Survey
The assessment of students' learning was done in the form of an individually-submitted one-to-two page laboratory report on the module. The intention was to draw students' attention to identifying and summarizing the most important results of a simulation study. This is because the output generated by Aspen HYSYS is typically long and dense and, therefore, requires some practice and conceptual understanding for the proper interpretation of the simulation results. The reports were due at the end of the laboratory session itself for the purpose of ensuring that students do not unnecessarily spend too much time working on the report, besides minimizing the possibility of students plagiarizing the reports of others, especially in the case of students who are absent from a laboratory session.

In addition to assessing the students' learning, each module assessed every week with the aid of a survey that was prepared at the beginning of the Fall term and was administered at the end of each module. The modules will also be assessed as a whole entity through another survey that will take place at the end of the CHEG 491 course (i.e. Spring 2012). In order to further assess the modules, a survey will be delivered to faculty members who taught simulation based courses (e.g. gas engineering, separation processes, and petroleum refining) in order to evaluate changes in students' proficiency in the use of process simulation tools compared to previous years. Such assessment will focus on answering questions such as: Does the implementation of the new modules increase the students' proficiency in using simulation tools, the proficient interpretation of the results of such tools, and enthusiasm towards the use of such tools.

After the completion of the ten modules, a survey was conducted at the end of the Fall 2011 term. The response rate was promising with an average rate of 88%. The survey consists of six questions stated as follows:

1. The module was easy to follow and clearly defined and structured.
2. The module objectives were achieved during the lab.
3. The module is very helpful in the simulation part of my design project.
4. The time required to cover the module objectives inside the lab is acceptable.
5. The instructor is knowledgeable, helpful and supportive
6. I would recommend this module to others

The above questions were asked for each of the 10 modules and measured against 4 responses' categories, namely: Strongly Agree, Agree, Disagree, and Strongly Disagree. The obtained results are discussed in the following section.

5. Results and Discussion
The results of the conducted survey are exhibited in Tables 1–6. Looking at the obtained results it can be concluded that students found these modules to be extremely beneficial in enhancing their learning in chemical engineering education especially in the area of process simulation and design. This can be evident through the high percentage of the Strongly Agree and Agree categories. In fact for each of the modules, the average percentage of the Strongly

Agree responses by the students is always higher than the Agree responses. On the contrary, the average percentage of the Strongly Disagree responses is almost zero and for the Disagree category is lower than 2%. The standard deviation for each module, which is the deviation from the average, was also computed and found to be minimal. The maximum standard deviation value reported was around 12%. All these values indicate that objectives of the modules were successfully met.

The findings obtained from this survey also confirm that students were able to learn and realize several ABET-related outcomes. These achieved learning outcomes include:
• Create and understand mathematical descriptions of physical phenomena.
• Scale variables and perform order-of-magnitude analysis.
• Structure and solve complex problems.
• Develop estimates and assumptions in facing open-ended problems.
• Manage large amounts of messy and noisy data including missing data and information.
• Resolve complex and sometimes contradictory issues in process design involving
• Sensitivity of solutions to the assumptions made, uncertainty in data, 'what-if' questions and possibilities, and process optimisation in general.
• Perform economic analysis.

Acquiring the above outcome is critical for the PI student as the institution has adopted to follow ABET accreditation rules.

Table 1: Response to "The module was easy to follow and clearly defined and structured?" question

Module No.	Number of Students responded	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
1	50	74.0	24.0	2.0	0.0
2	49	46.9	49.0	4.1	0.0
3	46	45.7	52.2	2.2	0.0
4	54	57.4	37.0	5.6	0.0
5	36	63.9	30.6	2.8	0.0
6	47	74.5	23.4	2.1	0.0
7	18	90.0	10.0	0.0	0.0
8	48	62.5	37.5	0.0	0.0
9	41	71.0	27.0	2.0	0.0
10	53	77.4	22.6	0.0	0.0

Table 2: Response to "The module objectives were achieved during the lab?" question

Module No.	Number of Students responded	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
1	50	64.0	36.0	0.0	0.0
2	49	44.9	49.0	2.0	0.0
3	46	50.0	50.0	0.0	0.0
4	54	59.3	40.7	0.0	0.0
5	36	61.1	36.1	0.0	0.0
6	47	68.1	31.9	0.0	0.0
7	18	75.0	25.0	0.0	0.0
8	48	64.6	31.3	4.2	0.0
9	41	59.0	41.0	0.0	0.0
10	53	75.5	20.8	3.8	0.0

Table 3: Response to "The module is very helpful in the simulation part of my design project?" question

Module No.	Number of Students responded	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
1	50	72.0	26.0	2.0	0.0
2	49	42.9	53.1	4.1	0.0
3	46	47.8	52.2	0.0	0.0
4	54	48.1	51.9	0.0	0.0
5	36	66.7	30.6	0.0	2.8
6	47	70.2	29.8	0.0	0.0
7	18	85.0	10.0	5.0	0.0
8	48	81.3	16.7	2.1	0.0
9	41	66.0	34.0	0.0	0.0
10	53	73.6	26.4	0.0	0.0

Table 4: Response to "The time required to cover the module objectives inside the lab is acceptable?" question

Module No.	Number of Students responded	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
1	50	60.0	34.0	6.0	0.0
2	49	28.6	63.3	0.0	8.2
3	46	43.5	47.8	8.7	0.0
4	54	53.7	46.3	0.0	0.0
5	36	58.3	36.1	2.8	2.8
6	47	66.0	29.8	4.3	0.0
7	18	90.0	10.0	0.0	0.0
8	48	52.1	39.6	8.3	0.0
9	41	56.0	37.0	5.0	2.0
10	53	47.2	49.1	3.8	0.0

Table 5: Response to "The instructor is knowledgeable, helpful and supportive?" question

Module No.	Number of Students responded	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
1	50	80.0	20.0	0.0	0.0
2	49	67.3	32.7	0.0	0.0
3	46	58.7	41.3	0.0	0.0
4	54	64.8	35.2	0.0	0.0
5	36	69.4	27.8	0.0	2.8
6	47	70.2	29.8	0.0	0.0
7	18	90.0	10.0	0.0	0.0
8	48	83.3	16.7	0.0	0.0
9	41	68.0	32.0	0.0	0.0
10	53	83.0	17.0	0.0	0.0

Table 6: Response to "I would recommend this module to others?" question

Module No.	Number of Students responded	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
1	50	60.0	38.0	2.0	0.0
2	49	40.8	59.2	0.0	0.0
3	46	43.5	56.5	0.0	0.0
4	54	51.9	46.3	1.9	0.0
5	36	61.1	36.1	0.0	2.8
6	47	63.8	36.2	0.0	0.0
7	18	80.0	20.0	0.0	0.0
8	48	77.1	22.9	0.0	0.0
9	41	54.0	46.0	0.0	0.0
10	53	69.8	30.2	0.0	0.0

6. Conclusion and Future Work

This report focuses on enhancing students' computational knowledge in the area of process simulation and design. The goal was achieved through the development of new process simulation modules as well as associated teaching materials that were integrated within the chemical engineering capstone design course. Ten set of modules were developed and integrated horizontally and vertically in a way that the chemical engineering principles are stressed and reinforced. To measure the effectiveness of the design course enhancement, a survey was carried out outlining six measuring criteria. The response rate was high and the majority of the examined students responded positively with more than 70% strongly agreeing that the developed modules were enormously beneficial. In future, additional modules could be added such as flowsheet optimization and more case studies in the area of product design.

Acknowledgements

References

Armstrong, R.C., A vision of the curriculum of the future. *Chemical Engineering Education*, 40(3), pp. 104–109, 2006.

Seider, W.D., J.D. Seader, and D.R. Lewin, Product and Process Design Principles: Synthesis, Analysis, and Evaluation. New York: John Wiley & Sons, 2004.

Mah, R.S.H. and D.M. Himmelblau, Role and impact of computers in engineering education, In Carnahan, Brice. *Computers in Chemical Engineering Education.* Austin, Texas: CACHE, 1996.

CACHE (Computer Aids for Chemical Engineering Education) Corporation, Computing through the curriculum: an integrated approach for chemical engineering [Textfile]. Retrieved July 11, 2006 from the World Wide Web: http://www.che.utexas.edu/cache/Edgar-computing%20through.html, 2004.

Edgar, T.F., Enhancing the undergraduate computing experience, *Chemical Engineering Education,* 40(3), pp. 231–238, 2006.

Khor, C.S., A. Elkamel, and W.A. Anderson, Incorporating the systems approach in future undergraduate chemical engineering education curriculum: illustration via computer-aided process simulation laboratory exercises, *World Review of Science, Technology and Sustainable Development*, 5(3/4), pp. 402–413, 2008.

Edgar, T. F., B. A. Ogunnaike, J. J. Downs, K. R. Muske, and B.W. Bequette, Renovating the undergraduate process control course. *Computers & Chemical Engineering*, 30, pp. 1749–1762, 2006.

Wankat, P.C., Integrating the use of commercial simulators into lecture courses, Journal *of Engineering Education,* 91 (1), 2002. Retrieved February 10, 2007 from the World Wide Web: http://www.che.utexas.edu/cache/newsletters/spring2002_integrating.pdf.