AC 2012-3670: ENGINEERING FUTURE CHEMICAL ENGINEERS: INCORPORATION OF PROCESS INTENSIFICATION CONCEPTS INTO THE UNDERGRADUATE CURRICULUM

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Engineering Future Chemical Engineers: Incorporation of Process Intensification Concepts into the Undergraduate Curriculum: Year 3 Activities

Abstract

Year 3 activities focused on incorporating concepts of process intensification into four chemical engineering courses are presented. These activities provide undergraduate chemical engineers with an introduction to process intensification, and the opportunity to learn about key aspects of combining processes/operations to achieve enhancements in energy efficiency, improved safety, utilization of resources and reduction of capital costs, waste generation, and energy consumption. Process intensification involves thinking about chemical processing in new ways such that (1) recognition of inherent limitations imposed by using sequential unit operations to accomplish chemical and/or physical transformations is achieved; and (2) methods of concurrently performing more than one unit operation are considered. This requires undergraduates to think in different ways about the processes they have learned about in their traditional unit operations courses. Process intensification is essential to industrial competitiveness as it can enhance safety, increase operating efficiency, lower energy usage, reduce capital costs, reduce waste emissions and process hazards, or encompass several of these benefits. Improving processes by process intensification requires engineers to integrate many fundamental concepts and go beyond traditional unit operations. Through activities focused on process intensification, global learning and the ability of our students to synthesize knowledge from different courses are strengthened.

Four core chemical engineering courses are targeted: fluid flow operations; heat transfer operations; mass transfer operations; and chemical reactor design. Over the course of this curriculum improvement project, activities/modules have been developed and incorporated into each course. Each activity/module focuses on a particular element from the process intensification spectrum and these are also designed to enhance vertical concept integration. Assessment data collected from the implementation of activities during Years 1 and 2 will also be presented.

Project Activities - Year 3

Kick Off Activity

At the start of the fall semester, Dr. Kishori Deshpande, Senior Research Engineer in Engineering Sciences at The Dow Chemical Company, visited the MSU campus and gave an invited presentation entitled "Achieving Sustainability through Process Intensification: An industrial perspective." During the seminar, Dr. Deshpande presented case studies of successful implementation of process intensification concepts at Dow. Approximately 75 students and faculty were in attendance at the seminar.

Fluid Flow Operations

The instructional module developed for year 3 for the fluids course will focus on the flow fields generated by centrifugal action. The traditional course content includes exposure to the use of a centrifugal field to separate two immiscible liquids that possess densities that differ only slightly from one another [1]. However, the use of the centrifugal field is presented only in the context of its effect on hydrostatic equilibrium. The use of centrifugal fields in chemical engineering to enhance processes through minimization of mass transfer resistance has applications in both separations and in chemical reactors. As a prelude to examination of two key process intensification technologies, the HiGEE separator (mass transfer operations) and the spinning disk reactor (chemical reactor design), some exposure to the flow fields generated by centrifugal action is necessary. The introduction of the relevant coordinate system will be required. An overview of the development of the velocity profiles for each application will be provided, with specific activities examining influence of field strength and fluid properties on the fluid velocity profile. This activity will be conducted during the Fall 2012 semester.

Heat Transfer Operations

During year 3 in the Heat Transfer Operations course, instructional modules developed under the project will be used (3rd cycle for Heat Transfer Operations is the Spring 2012 semester). One module focuses on heat transfer in thin films and is designed to allow students to identify controlling phenomena with different terms in the energy balance. The module for year 3 will focus on a conceptual design of heat exchangers embodying the tenants of process intensification [2-4]. This activity will be completed during the Spring 2012 semester.

Mass Transfer Operations

During year 3 in the Mass Transfer Operations course, three instructional modules developed under the NSF-CCLI project will be used (the 3rd cycle for Mass Transfer Operations is the Spring 2012 semester). The first module examines the coupling of reaction and separation as implemented in reactive distillation. The instructional module presents the basic operation of a reactive distillation column and students complete a homework assignment examining an industrial application of the technology. The second module presents instruction regarding divided wall columns, and how this mode of construction/operation allows for increased energy efficiency. The third instructional module examines the concept of hybrid separation processes, where two distinct separation processes are coupled together, each operating in the regime where they offer superior performance. Review material for each of the individual separation processes is presented, along with basic process configuration. The advantages/disadvantages of each process are reviewed and limitations/constraints are also presented. Three case studies where hybrid separations have been successfully employed in industry are included in the module. These case studies examine the coupling of 1) pressure swing adsorption and membrane permeation for separation of nitrogen from natural gas; 2) distillation and vapor permeation or distillation and pervaporation for the separation of ethanol and water, and 3) distillation/facilitated transport for the separation of propane and propylene.

Chemical Reactor Design

During year 3, three instructional modules developed under the NSF-CCLI project were used in the Chemical Reactor Design course. The first module examined coupling of chemical reactions where either energy or mass or both energy and mass were exchanged to provide for increased energy and materials utilization efficiency. The second module examined the coupling of separation and reaction through the use of simulated moving bed reactor technology. The module provides background information on adsorption processes and how they work and are designed; the disadvantages of moving bed technology with regards to solids, and how simulated moving bed technology overcomes these disadvantages. The coupling of the simulated moving bed separation technology with reaction is also examined with a case study of p-xylene production [5].

The third instructional module focuses on novel reactor configurations. For the production of fine chemicals and pharmaceuticals, chemical reactions are often carried out in batch rather than continuous mode. Two novel alternatives are the cavitational reactor [6] and the spinning disk reactor [7]. These utilize sonication and high gravity, respectively, to enhance mass transfer in the reactor, leading to significant performance improvements over batch reactors. The module provides instruction on the phenomena exploited to achieve the improvements in each reactor type and basic configuration as well as an overview of technology applications and commercial use. Reaction system yields/selectivity for the alternative reactors are compared to performance data for conventional reactors.

Assessment of Activities

Assessment results for Years 1-3 are discussed (see Table 1 for rotation of courses taught). Ratings of 269 students across 14 variables (Table 2-5) in all four classes (i.e., Mass Transfer Operations, Heat Transfer Operations, and Fluids Flow Operations, and Reactor Design) early in the semester (pre) and at the end of the semester (post) used a survey that consisted of ratings of 0 (Disagree), 1 (Somewhat Agree), 2 (Somewhat Agree), and 3 (Agree). Because this study is a multi-year study, students were enrolled in classes at various stages as they matriculated through the program of study for Chemical Engineering. Future studies will examine the students as they progressed through the program using single-subject design analyses. The current study examines only individual course results. Thus, Tables 2-5 provide the means at pre and post and the degree of change across rating times for each class during the semesters taught and as a total of all students enrolled in each class. For clarity, only ratings for all sections of a class (e.g., across all semesters) will be presented below.

At pre instruction, the ratings (depending upon variable) of a total of 52 to 57 students were matched across the two semesters in Heat Transfer (see Table 2). Students rated all 14 areas at higher levels at post instruction than at pre instruction with the exception of *Easily Presented* (Pre M = 1.95, SD = 0.69 and Post M = 1.89, SD = 0.75) showing that most students did not perceive the material to be easily presented by the instructor. However, only 6 of the 14 variable ratings were significantly higher at post instruction relative to pre instruction. These include: (a) *Used Activities to Illustrate*, $t(1,55) = (-4.69)$, $p = 0.000$; (b) *Furthered Understanding*, $t(1,54) = (-2.48)$, $p = 0.016$; (c) *Encouraged to Use Analysis*, $t(1, 51) = (-3.77)$, $p = 0.000$; (d) *Encouraged to Use Synthesis*, $t(1, 53)= (-2.84)$, $p = 0.042$; (e) *Can be Flexible*, $t(1, 56) = (-2.68)$, $p = 0.010$; and (f) *Can Integrate Outside Info*, $t(1, 55) = (-2.69)$, $p = 0.010$ (see Table 6).

In Mass Transfer, data could be matched (depending upon variable) for a total of 56 to 59 students across the two semesters. On average, all students provided lower post instruction than pre instruction ratings. Notably, the lowest ratings across both semesters were in *Used Activities to Illustrate* (post instruction M = 1.30, SD = 0.93), *Furthered Understanding* (post instruction M = 1.77, SD = 1.02), and *Encouraged to Use Synthesis* (post instruction M = 1.98, SD = 0.87). These ratings indicate students, on average Agreed Somewhat or less on these variables.

Relative to pre instruction, ratings at post instruction were not significantly different across both semesters for any of the variables with the exception of three: (a) *Used Activities to Illustrate*, $t(1, 56) = 2.08$, $p = 0.042$; (b) *Encouraged to Problem Solve*, $t(1, 58) = 2.08$, $p = 0.042$; and (c) *Can Use Analysis*, $t(1, 56) = 2.32$, $p = 0.024$ (see Table 7).

During the first semester the Fluid Flow Operations course was taught (Semester 3) with the intensification lecture component included, multiple student ratings were at or below Somewhat Agree (M range 1.51 to 2.28 on all 0 to 3 ratings and M range 4.07 to 4.40 on 0 to 6 ratings). Only two variables were significantly different pre to post instruction (both with lower ratings at post instruction): (a) *Easily Presented*, $t(1, 42) = 4.65$, $p = 0.000$ and (b) *Furthered Understanding*, $t(1, 42) = 2.96$, $p = 0.005$ (see Table 8). For this past semester (Semester 5) when the concept of process intensification was introduced, but with no subsequent module presentations, students rated only two variables lower (*Used Activities to Illustrate* and *Encouraged to Modify Materials/Knowledge*), neither was lower to a significant degree ($\Delta = (-0.08)$ and (-0.03), respectively). However, seven of the variables were rated significantly higher, pre to post instruction, by students: (a) *Encouraged to be Flexible*, $t(1, 38) = (-2.40)$, $p < 0.021$; (b) *Encouraged to Problem Solve,* $t(1, 48) = (-2.40)$, $p < 0.021$; (c) *Encouraged to Integrate Outside Materials/Knowledge,* $t(1, 38) = (-2.93)$, $p < 0.006$; (d) *Encouraged to Use Analysis,* $t(1, 38) = (-5.23)$, $p < 0.000$; (e) *Encouraged to Use Synthesis,* $t(1, 38) = (-4.08)$, $p < 0.000$; (f) *Can be Flexible,* $t(1, 38) = (-2.70)$, $p < 0.010$; and (g) *Can Use Synthesis,* $t(1, 38) = (-3.14)$, $p < 0.003$ (see Table 9).

In Reactor Design (depending upon variable) a total 71 to 73 ratings could be paired across two semesters. On average across both semesters, relative to pre instruction, students rated all areas higher at post instruction, with five variables rated significantly higher on average. These variables included: (a) *Encouraged to be Flexible*, $t(1, 72) = (-2.08)$, $p < 0.041$; (b) *Encouraged to Problem Solve,* $t(1, 72) = (-2.08)$, $p < 0.041$; (c) *Encouraged to Integrate Outside Materials/Knowledge,* $t(1, 72) = (-2.00)$, $p < 0.049$; (d) *Encouraged to Use Analysis,* $t(1, 72) = (-2.48)$, $p < 0.016$; and (e) *Can Use Synthesis,* $t(1, 71) = -2.22$, $p < 0.030$ (see Table 10).

In the Reactor Design (both semesters) and Mass Transfer (one semester) courses, an integration activity was presented to students (n=73 and 36, respectively) and an evaluation of knowledge was administered pre and post activity. This activity consisted of 4 questions, 3 which possessed a single correct response and 1 that had multiple correct responses (select all that are correct). Thus, the maximum score possible was 6. The responses were grouped according to a single correct response on three questions (scored right or wrong; e.g., 3-question scores ranged from 0 to 3) and a multiple-choice question (scored 1 for each correct selection, e.g., 0 to 3). A paired sample t test was calculated to determine differences pre to post. In the Reactor Design course, students scored significantly better during post on the single response questions ($M = 2.68$, $SD = 0.72$) than during the pre activity ($M = 1.39$, $SD = 0.74$), $t(1, 92) = (-12.78)$, $p < 0.000$ and on the multiple response questions ($M = 1.41$, $SD = 0.91$ and $M = 2.82$, $SD = 0.47$, pre and post activity respectively), $t(1, 92) = (-15.10)$, $p < 0.000$. In the Mass Transfer course, students scored significantly better at post on the single response questions ($M = 2.61$, $SD = 0.77$) than at pre activity ($M = 1.28$, $SD = 0.66$), $t(1, 35) = (-8.94)$, $p < 0.000$ and on the multiple response questions ($M = 1.67$, $SD = 0.76$ and $M = 2.42$, $SD = 0.69$, pre and post activity respectively), t(1,

35) = (-5.84), $p < 0.000$. Results of the paired samples test are presented in Table 11 for both courses.

Integrity checks with class activities conducted two times during the semester in both courses indicated instructors were rated at relatively high levels across all variables (inter observer agreement at greater than 90% for all courses).

Summary/Discussion

Overall, students' perceptions are high across all 14 variables in all semesters that all four courses were taught (*M* range = 1.24-2.81 and 1.05-2.89, pre and post, respectively on a 0 to 3 point scale, 3=higher scores) and *M* range = 4.04-5.11 and 3.90-5.44, pre and post, respectively only a 0 to 6 point scale, 6=higher scores). There does appear to be a change in students' perceptions of the courses and their own abilities within specific classes, sometimes a positive change and sometimes a negative change. For students enrolled in Heat Transfer, the data show there is a gain in perception that the activities illustrate concepts and that the information is useful to further their understanding. However, these improved perceptions are not necessarily present in the perceptions of students in other courses. Additionally, students in Heat Transfer also appeared to perceive increases in three areas: encouragement to use analysis and synthesis; their ability to be flexible; and their ability to integrate outside information. Students enrolled in Reactor Design showed growth in encouragement to problem solve, to be flexible, to integrate outside materials/knowledge, and to use analysis. There was also an improvement of students' perception of their ability to synthesize information in Reactor Design.

There were a few situations where students' perceptions decreased within the class. Specifically, in Mass Transfer, students perceptions of activities to illustrate concepts decreased as did perception of encouragement to problem solve and their ability to use analysis. In Fluid Flow, students' perceptions decreased in the usefulness of information to further their understanding.

Students in Mass Transfer and Reactor Design showed a growth in knowledge pre to post intensification instruction as indicated by significant change in their quiz scores.

It is important to recognize that because ratings were universally positive for all variables in all classes, a few lower ratings should not be a cause for concern. Nor is there yet sufficient information to determine specifics about the cause of decreased or increased perceptions. Further analyses will need to be conducted to examine relationships between student characteristics (e.g., course sequence, GPA) and teacher evaluations and classroom observations.

Conclusion

Integration of key concepts related to process intensification across multiple core chemical engineering courses provides the opportunity for students to become both familiar with the tenets of process intensification as well as be equipped to examine intensified process alternatives during the senior design courses. As students progress through the four-course sequence, it is expected that their foundation will become stronger in these tenets and they will be better equipped to face the challenges that will be present when they graduate and enter the chemical engineering workforce.

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Table 1 Semesters Courses Were Taught and Number of Student Participants

Semester Taught	**# Students**
Heat Transfer	
Spring Semester 2	34
Spring Semester 4	23
Total	57
Mass Transfer	
Spring Semester 2	37
Spring Semester 4	21
Total	58
Fluid Flow	
Fall Semester 3	43
Fall Semester 5	39
Total	82
Reactor Design	
Fall Semester 3	37
Fall Semester 5	36
Total	73
Total Students	
Total Student Participants Across all Courses	269

Table 2 Change (Δ) Pre to Post in Students' Mean Perceptions Pre to Post in Heat Transfer Semester 2 (*n*=34), Semester 4 (*n*=23), and Total (*n*=57)

	Semester 2				**Semester 4**				**Total**		
Variable	**Pre**	**Post**	**Δ**		**Pre**	**Post**	**Δ**		**Pre**	**Post**	**Δ**
Easily Presented	1.88	1.88	0.00		2.04	1.91	-0.13		1.95	1.89	-0.06
Used Activities to Illustrate	1.24	2.56	**1.32**		2.18	1.91	-0.27		1.61	2.30	**0.69**
Furthered Understanding	1.58	2.52	**0.94**		2.18	1.77	**-0.41**		1.82	2.22	**0.40**
Encouraged to Modify Materials/Knowledge	2.32	2.35	0.03		2.13	2.26	0.13		2.25	2.32	0.07
Encouraged to be Flexible	2.35	2.53	0.18		2.30	2.50	0.20		2.33	2.52	0.19
Encouraged to Problem Solve	2.35	2.53	0.18		2.30	2.50	0.20		2.33	2.52	0.19
Encouraged to Integrate Outside Materials/ Knowledge	2.15	2.35	0.20		2.04	2.22	0.18		2.11	2.30	0.19
Encouraged to Use Analysis	4.17*	4.87*	**0.70**		4.14*	4.73*	**0.59**		4.15*	4.81*	**0.66**
Encouraged to Use Synthesis	2.06	2.41	0.35		2.27	2.45	0.18		2.15	2.43	**0.28**
Can be Flexible	1.97	2.35	**0.38**		2.04	2.26	0.22		2.00	2.32	**0.32**
Can Use Problem Solving	2.21	2.44	0.23		2.26	2.39	0.13		2.23	2.42	0.19
Can Integrate Outside Info	4.27*	4.67*	0.40		4.04*	4.61*	**0.57**		4.18*	4.64*	**0.46**
Can Use Analysis	1.94	2.30	**0.36**		2.26	2.30	0.04		2.07	2.30	0.23
Can Use Synthesis	2.13	2.32	0.19		2.09	2.35	0.26		2.11	2.33	0.22

Note: * indicates a rating scale of 0-6 (6=higher ratings), all other ratings on a scale of 0-4 (4=higher ratings), bold indicates significant ($p \leq 0.05$) difference.

Table 3 Change (Δ) Pre to Post in Students' Mean Perceptions Pre to Post in Mass Transfer Semester 2 (*n*=37), Semester 4 (*n*=21), and Total (*n*=58)

	Semester 2				**Semester 4**				**Total**		
Variable	**Pre**	**Post**	**Δ**		**Pre**	**Post**	**Δ**		**Pre**	**Post**	**Δ**
Easily Presented	2.49	2.32	-0.17		1.95	2.05	0.10		2.29	2.22	-0.07
Used Activities to Illustrate	1.67	1.44	-0.23		1.33	1.05	-0.28		1.54	1.30	**-0.24**
Furthered Understanding	2.06	1.92	-0.14		1.76	1.52	-0.24		1.95	1.77	-0.18
Encouraged to Modify Materials/ Knowledge	2.57	2.35	-0.22		2.23	2.36	0.13		2.44	2.36	-0.08
Encouraged to be Flexible	2.38	2.19	-0.19		2.18	1.95	-0.23		2.31	2.10	-0.21
Encouraged to Problem Solve	2.41	2.16	-0.25		2.18	1.95	-0.23		2.32	2.08	**-0.24**
Encouraged to Integrate Outside Materials/Knowledge	2.27	2.08	-0.19		1.86	2.14	0.28		2.12	2.10	-0.02
Encouraged to Use Analysis	4.06*	3.71*	-0.35		4.05*	3.90*	-0.15		4.05*	3.79*	-0.26
Encouraged to Use Synthesis	2.27	2.11	-0.16		1.90	1.76	-0.14		2.14	1.98	-0.16
Can be Flexible	2.33	2.39	0.06		2.09	2.18	0.09		2.24	2.31	0.07
Can Use Problem Solving	2.59	2.35	**-0.24**		1.91	2.18	0.27		2.34	2.29	-0.05
Can Integrate Outside Info	4.76*	4.43*	-0.33		4.36*	4.55*	0.19		4.61*	4.47*	-0.14
Can Use Analysis	2.51	2.06	**-0.45**		2.18	2.23	0.05		2.39	2.12	**-0.27**
Can Use Synthesis	2.35	2.35	0.00		2.05	2.18	0.13		2.24	2.29	0.05

Note: * indicates a rating scale of 0-6 (6=higher ratings), all other ratings on a scale of 0-4 (4=higher ratings), bold indicates significant ($p \leq 0.05$) difference.

Table 4 Change (Δ) Pre to Post in Students' Mean Perceptions Pre to Post in Fluid Flow Semester 3 (*n*=43) and Semester 5 (*n*=39)

	Semester 3				Semester 5		
Variable	**Pre**	**Post**	**Δ**		**Pre**	**Post**	**Δ**
Easily Presented	2.56	1.81	**-0.75**		2.21	2.50	0.29
Used Activities to Illustrate	1.70	1.60	-0.10		2.08	2.00	-0.08
Furthered Understanding	1.98	1.51	**-0.47**		2.13	2.37	0.24
Encouraged to Modify Materials/Knowledge	2.26	2.28	0.02		2.54	2.51	-0.03
Encouraged to be Flexible	2.19	2.26	0.07		2.31	2.62	**0.31**
Encouraged to Problem Solve	2.19	2.26	0.07		2.31	2.62	**0.31**
Encouraged to Integrate Outside Materials/Knowledge	2.47	2.33	-0.14		2.23	2.54	**0.31**
Encouraged to Use Analysis	4.42*	4.07*	-0.35		4.05*	4.95*	**0.90**
Encouraged to Use Synthesis	2.24	1.95	-0.29		1.82	2.54	**0.72**
Can be Flexible	2.09	1.91	-0.18		2.28	2.62	**0.34**
Can Use Problem Solving	2.26	2.21	-0.05		2.49	2.67	0.18
Can Integrate Outside Info	4.28*	4.40*	0.12		4.62*	4.97*	0.35
Can Use Analysis	2.13	1.90	-0.23		2.46	2.54	0.08
Can Use Synthesis	2.15	1.95	-0.20		2.18	2.51	**0.33**

Note: * indicates a rating scale of 0-6 (6=higher ratings), all other ratings on a scale of 0-4 (4=higher ratings), bold indicates significant ($p \leq 0.05$) difference.

Table 5 Change (Δ) Pre to Post in Students' Mean Perceptions Pre to Post in Reactor Design Semester 3 (*n*=37), Semester 5 (*n*=36), and Total (*n*=73)

	Semester 3				**Semester 5**				**Total**		
Variable	**Pre**	**Post**	**Δ**		**Pre**	**Post**	**Δ**		**Pre**	**Post**	**Δ**
Easily Presented	2.81	2.73	-0.08		2.67	2.89	**0.22**		2.74	2.81	0.07
Used Activities to Illustrate	2.11	1.90	**-0.21**		2.19	2.36	0.17		2.15	2.13	-0.02
Furthered Understanding	2.31	2.14	-0.17		2.40	2.63	**0.23**		2.35	2.38	0.03
Encouraged to Modify Materials/Knowledge	2.62	2.57	-0.05		2.47	2.75	**0.28**		2.55	2.66	0.11
Encouraged to be Flexible	2.62	2.76	0.14		2.61	2.83	**0.22**		2.62	2.79	**0.17**
Encouraged to Problem Solve	2.62	2.76	0.14		2.61	2.83	**0.22**		2.62	2.79	**0.17**
Encouraged to Integrate Materials/Knowledge	2.68	2.70	0.02		2.42	2.67	**0.25**		2.55	2.68	**0.13**
Encouraged to Use Analysis	5.00*	5.00*	0.00		4.72*	5.44*	**0.72**		4.86*	5.22*	**0.36**
Encouraged to Use Synthesis	2.68	2.57	-0.11		2.51	2.74	**0.23**		2.60	2.65	0.05
Can be Flexible	2.62	2.46	-0.16		2.58	2.75	0.17		2.60	2.60	0.00
Can Use Problem Solving	2.62	2.57	-0.05		2.56	2.86	**0.30**		2.59	2.71	0.12
Can Integrate Outside Info	5.19*	5.11*	-0.08		4.86*	5.44*	**0.58**		5.03*	5.27*	0.24
Can Use Analysis	2.53	2.47	-0.06		2.53	2.69	0.16		2.53	2.58	0.05
Can Use Synthesis	2.46	2.54	0.08		2.34	2.66	**0.32**		2.40	2.60	**0.20**

Note: * indicates a rating scale of 0-6 (6=higher ratings), all other ratings on a scale of 0-4 (4=higher ratings), bold indicates significant ($p \leq 0.05$) difference.

Table 6 Paired Samples Test for Heat Transfer Across Both Semesters

Pre to Post Variable	Differences				t	df	Sig. (2-tailed)
	Mean	Std. Dev.	95% Confidence Interval of the Difference				
			Lower	Upper			
Used Activities to Illustrate	-0.70	1.11	-0.99	-0.39	-4.69	55	0.000
Furthered Understanding	-0.40	1.20	-0.72	-0.08	-2.48	54	0.016
Encouraged to Use Analysis	-0.65	1.25	-1.00	-0.31	-3.77	51	0.000
Encouraged to Use Synthesis	-0.28	0.98	-0.55	-0.01	-2.08	53	0.042
Can be Flexible	-0.32	0.89	-0.55	-0.08	-2.68	56	0.010
Can Integrate Outside Info	-0.46	1.29	-0.81	-0.12	-2.69	55	0.010

Table 7 Paired Samples Test for Mass Transfer Across Both Semesters

Pre to Post Variable	Differences				t	df	Sig. (2-tailed)
	Mean	Std. Dev.	95% Confidence Interval of the Difference				
			Lower	Upper			
Used Activities to Illustrate	0.24	0.89	0.01	0.48	2.08	56	.042
Encouraged to Problem Solve	0.24	0.88	0.01	0.47	2.07	58	.042
Can Use Analysis	0.26	0.86	0.04	0.49	2.32	56	.024

Table 8 Paired Samples Test for Fluid Flow for Semester 3

Pre to Post Variable	Differences				t	df	Sig. (2-tailed)
	Mean	Std. Dev.	95% Confidence Interval of the Difference				
			Lower	Upper			
Easily Presented	0.74	1.05	0.42	1.07	4.65	42	.000
Furthered Understanding	0.47	1.03	0.15	0.78	2.96	42	.005

Table 9 Paired Samples Test for Fluid Flow for Semester 5

Pre to Post Variable	Differences				t	df	Sig. (2-tailed)
			95% Confidence Interval of the Difference				
	Mean	Std. Dev.	Lower	Upper			
Encouraged to Flexible	-0.31	0.80	-0.57	-0.05	-2.40	38	.021
Encouraged to Problem Solve	-0.31	0.80	-0.57	-0.05	-2.40	38	.021
Encouraged to Integrate Outside Materials/Knowledge	-0.31	0.66	-0.52	-0.10	-2.93	38	.006
Encouraged to Use Analysis	-0.90	1.07	-1.24	-0.55	-5.23	38	.000
Encouraged to Use Synthesis	-0.72	1.10	-1.07	-0.36	-4.08	38	.000
Can be Flexible	-0.33	0.77	-0.58	-0.08	-2.70	38	.010
Can Use Synthesis	-0.33	0.66	-0.55	-0.12	-3.14	38	.003

Table 10 Paired Samples Test for Reactor Design Across Semesters

Pre to Post Variable	Differences				t	df	Sig. (2-tailed)
			95% Confidence Interval of the Difference				
	Mean	Std. Dev.	Lower	Upper			
Encouraged to Flexible	-0.18	0.73	-0.35	-0.01	-2.08	72	.041
Encouraged to Problem Solve	-0.18	0.73	-0.35	-0.01	-2.08	72	.041
Encouraged to Integrate Outside Materials/Knowledge	-0.14	0.58	-0.27	-0.00	-2.00	72	.049
Encouraged to Use Analysis	-0.36	1.23	-0.64	-0.07	-2.48	72	.016
Can Use Synthesis	-0.19	0.74	-0.37	-0.02	-2.22	71	.030

Table 11 Paired Samples Test for Pre to Post Responses to Knowledge Questions in Reactor Design and Mass Transfer

Pre to Post Variable	Differences				t	df	Sig. (2-tailed)
			95% Confidence Interval of the Difference				
	Mean	Std. Dev.	Lower	Upper			
Reactor Design Single Questions	-1.29	0.97	-1.49	-1.09	-12.78	92	.000
Reactor Design Multiple Question	-1.41	0.90	-1.59	-1.22	-15.10	92	.000
Mass Transfer Single Questions	-1.33	0.89	-1.64	-1.03	-8.94	35	.000
Mass Transfer Multiple Question	-0.75	0.77	-1.01	-0.49	-5.84	35	.000