Is Student Performance in CHE Core Courses Affected by Time Elapsed Since Completion of Material and Energy Balance Course Sequence?

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Is Student Performance in ChE Core Courses Affected by Time Elapsed Since Completion of Material and Energy Balance Course Sequence?

Abstract: *Material and energy balances are a foundational core subject in chemical engineering. This study explored the effect of time elapsed between the completion of material and energy balances and the start of four junior-level core chemical engineering courses. Two cohorts were tracked: one took material and energy balances as a single 4-credit course in the summer of 2014, the other as two 2-credit courses during the 2014/2015 academic year. During the Fall 2015 semester, the students from both cohorts were enrolled simultaneously in four junior-level core courses. The results show that the two cohorts had achieved comparable levels of performance in material and energy balances while they were taking it, but that the students who experienced about a four month time delay between the completion of material and energy balances and the beginning of the junior-level core courses achieved, on average, higher success in the core courses than did the students who experienced about a 13 month time delay.*

Background

Material and energy balances are foundational subjects in chemical engineering. A survey[1] conducted during the 2010/2011 academic year revealed that 79 % of responding chemical engineering (ChE) programs offered a single course in material and energy balances, with other programs offering a multi-course sequence. The survey also revealed that the course (or first course if a sequence is offered) is most commonly offered during the first semester of the sophomore year. The ChE curriculum at Rowan University includes a two-course sequence for sophomores: Principles of Chemical Processes (PCP) I and II, covering material and energy balances, respectively. These courses each have one 75-minute period and one 150-minute period per week, with the double periods being largely dedicated to group problem-solving activities. Both courses have long used Felder and Rousseau[2] as the adopted textbook. A minimum grade of C- in PCP I is a prerequisite for PCP II and a C- in PCP II is a prerequisite for almost every upper-level course in the core ChE curriculum.

In some years, when demand was sufficient, the chemical engineering department has offered PCP I and/or II during the summer. These summer offerings allowed sophomores who fell short of C- in either PCP I or II to catch up and remain on a 4-year path to graduation, and were also helpful for transfer students. In the summer of 2014, the department offered a 4-credit online, asynchronous course (titled Principles of Chemical Processes, or PCP) that combined the content of PCP I and II into a single course, again using the Felder and Rousseau text. The enrolled students included, as expected, transfer students and students who had fallen short of C- in either PCP I or II during the previous academic year. In addition, however, a number of rising sophomores also took the summer course. This was a new phenomenon that has several apparent benefits:

- From a student perspective, the summer course allows one to get ahead on degree requirements, freeing up time in the academic year to pursue a minor, dual major, concentration, semester abroad, etc.
- From a faculty perspective, increasing enrollment has in recent years placed a strain on resources, which is eased when some students take a course during the summer instead of during the academic year.

- From an administrative perspective, offering the summer course is both a service to students and a modest source of tuition revenue.

However, this practice also raised a concern. In the typical ChE curriculum, a student takes 5-6 engineering courses in the fall of the junior year, four of which build directly on PCP II. These junior-level core courses also have other significant prerequisites beyond PCP, including Fluid Mechanics, chemistry and math courses. Consequently, the students who took PCP in the summer after their first year could not immediately enroll in the junior-level core courses; they were missing other prerequisites that they acquired during their sophomore year. The concern is that a student who took PCP during the summer before his/her sophomore year may experience decreased retention of the course content due to the > 1 year delay between PCP and the junior year, compared to the bulk of the cohort that finished PCP II less than four months prior to the start of the junior year.

It has been shown[3] in other settings that increased time elapsed between courses can negatively impact retention of material. The authors are not aware of any published study related specifically to retention with respect to material and energy balances in the chemical engineering field. One possibly related study was the "spiral" sophomore curriculum that was developed at Worcester Polytechnic Institute and described in a series of publications.[4-6] The authors converted a series of 7-week courses that had been offered sequentially- covering material balances, equilibrium-staged separations, and thermodynamics- and implemented a project-based "spiral" sequence. Both sequences had the same number of courses and same schedule of contact hours and taken as a whole covered the same content. But in the "spiral" curriculum, the modular courses on material and energy balances, thermodynamics, and separations were replaced with a series of integrated courses in which these topics were addressed concurrently. One of the motivations for the new sequence was to address the phenomena of students succeeding in material and energy balances but not retaining the skills or recognizing the significance of the principles in the context of other courses. The spiral sequence of courses also included projects that were designed to require synthesis of these various topics. The assessment showed improved retention as a benefit of the spiral curriculum compared to the sequence of modular courses.[6] Project-based learning and problem-based learning have also been shown in other settings to improve retention, as summarized by Woods.[7] These facts are relevant to the current study in that the spring 2015 PCP II course included homework and a project completed by students in teams of 3-4, while the PCP course as offered in the summer of 2014 was an online course in which all assignments were individual and there was no team-based project.

This paper describes the results of an investigation comparing the performance of the rising sophomores who took the summer course to the performance of their peers who followed the typical academic-year curriculum. The research questions of the study are:

- What is the relationship between mastery of key principles in PCP (whether taken as one course or two) and performance in the fall junior-level core ChE courses?
- Is this relationship dependent upon the time elapsed between completion of PCP and beginning of the fall junior-level core ChE courses?

Cohorts

The two cohorts compared in this study will be termed the "summer cohort" and the "academic-year cohort".

- The summer cohort consists of 14 students who successfully completed PCP in the summer of 2014, earning a C- or better.

- The academic-year cohort currently consists of 34 students who successfully completed PCP I in the fall of 2014 and PCP II in the spring of 2015, earning C- or better in both courses.
- All of the students in both cohorts are full-time students majoring in ChE at Rowan University, and were enrolled in all four of the following junior-level core ChE courses in the fall of 2015: Chemical Engineering Thermodynamics I, Heat Transfer Operations, Separations I, and Process Fluid Transport.

Note that the purpose of the study is to examine the effect of lag time between successful completion of PCP and the beginning of the junior-level ChE core courses. Consequently, any student who repeated PCP for any reason was removed from the study, because "lag time" is ambiguous for such a student and the effect of repetition represents a confounding factor. In total, 64 students were enrolled in some or all of the junior-level core courses in the fall of 2015, but this paper presents data only for the 48 who met the criteria of one of the "cohorts" described above. Two sections were offered for each of the fall junior-level core courses, and each section contained exactly seven of the 14 summer cohort students and 16-18 of the 34 academic-year cohort students.

Data: Course Grades

Table 1 presents a comparison of the two cohorts using average course grades as the sole metric for student performance. The university scale for converting letter grades to grade point averages is A = 4.0, B = 3.0, C = 2.0, D = 1.0, F = 0.0. The university does use plus and minus modifiers (though there is no A+, F+ or F-), which are reflected in calculating a GPA by adding 0.3 for plus and subtracting 0.3 for minus.

Table 1: Average cumulative GPAs and GPAs earned in specific relevant courses for the two cohorts. Standard deviations are indicated with ±.

	Summer Cohort	**Academic Year Cohort**
Number of students	14	34
Cumulative GPA as of START of PCP	3.61 ± 0.39	3.62 ± 0.39
Cumulative GPA as of START of junior year	3.51 ± 0.41	3.53 ± 0.44
GPA in PCP I (2 credits)	N/A	3.52 ± 0.61
GPA in PCP II (2 credits)	N/A	3.01 ± 0.76
GPA in PCP (4 credits)	3.44 ± 0.37	N/A
GPA in Thermodynamics I	2.74 ± 1.25	3.21 ± 0.87
GPA in Separations I	2.99 ± 1.09	3.39 ± 0.99
GPA in Heat Transfer	2.73 ± 1.07	3.03 ± 0.84
GPA in Process Fluid Transport	2.99 ± 1.17	3.26 ± 0.80
Cumulative GPA in four junior core ChE courses	2.86 ± 1.12	3.21 ± 0.88

The 14 students in the "summer cohort" earned a cumulative GPA of 3.44 in the 4-credit summer PCP course, meaning that the average grade for these 14 students was slightly better than a B+. The 34 students in the academic-year cohort earned a cumulative GPA of 3.52 (B+) in the 2-credit PCP I and a 3.01 (B) the 2-credit PCP II, or a 3.27 cumulative GPA (B+) in the PCP sequence overall. Thus, the "summer" cohort earned slightly better grades in material and energy balances than did the academic-year cohort. However, Table 1 shows that the academic-year cohort out-performed the summer cohort in each of the four junior-level core courses, with the academic-year cohort earning a cumulative GPA in the four courses that was higher by 0.35. The differences are not statistically significant at a 95 % confidence level for each course performance viewed individually; however, when all of the course grades are aggregated, giving 56 data points for the summer cohort and 136 for the academic-year cohort, the difference is statistically significant ($p = 0.022$). This difference in performance in the junior-level core ChE courses cannot be attributed to a systematic difference between the two cohorts in overall academic performance, as Table 1 shows that the two cohorts were essentially indistinguishable in their performances in the first and second years of the curriculum overall.

Figure 1 shows a plot of the data for individual students, where the GPA in junior-level core ChE courses is plotted as a function of the GPA in material and energy balances. The *x*-axis for the summer cohort is simply their grade in that course (4.0 for A, 3.7 for A- etc.), while it is the average of the two grades in PCP I and PCP II for the academic-year cohort. As one would expect, there is significant scatter, but a correlation between grades in material and energy balances and grades in junior-level core ChE courses is apparent. Table 2 shows the linear regression statistics for the summer cohort, the academic-year cohort, and for all 48 students in both cohorts combined. The trend line for the summer cohort is strongly negatively influenced by two students who earned GPAs of roughly a1.0 in the junior-level core ChE courses. We note that if these two students are removed from the data set, the cumulative GPA of the summer cohort in all four junior-level core courses increases from 2.86 (the value that appears in Table 1) to 3.16. This result is still fractionally lower than the cumulative GPA of 3.21 for the academic-year cohort, but the difference is no longer statistically significant in this scenario. However, in the opinion of the authors, these two students should <u>not</u> be dismissed as "outliers" since they are precisely illustrative of the concern: these two students performed satisfactorily in the foundational course (B and B+ in PCP) but one year later struggled in all of the junior-level core ChE courses and did not earn the grades of C- or better that would allow them to continue to the second semester junior courses. Significantly:

- Of the 34 students in the academic-year cohort, 31 earned C- or better in all four of the junior-level core courses. Two earned a single D and succeeded in the other three courses. One earned a D or F in all four courses.
- Of the 14 students in the summer cohort, 11 earned a C- or better in all four of the junior-level core courses. One earned a single D and succeeded in the other three courses. The other two students earned, respectively, three and four D/F grades.
- 15 out of 34 students in the academic-year cohort earned a cumulative GPA in the four junior-level core courses that was equal to or greater than his/her GPA in the two PCP courses. Only four out of 14 students in the summer cohort earned a cumulative GPA in the four junior-level core courses that was equal to or greater than the grade point represented by his/her grade in PCP.

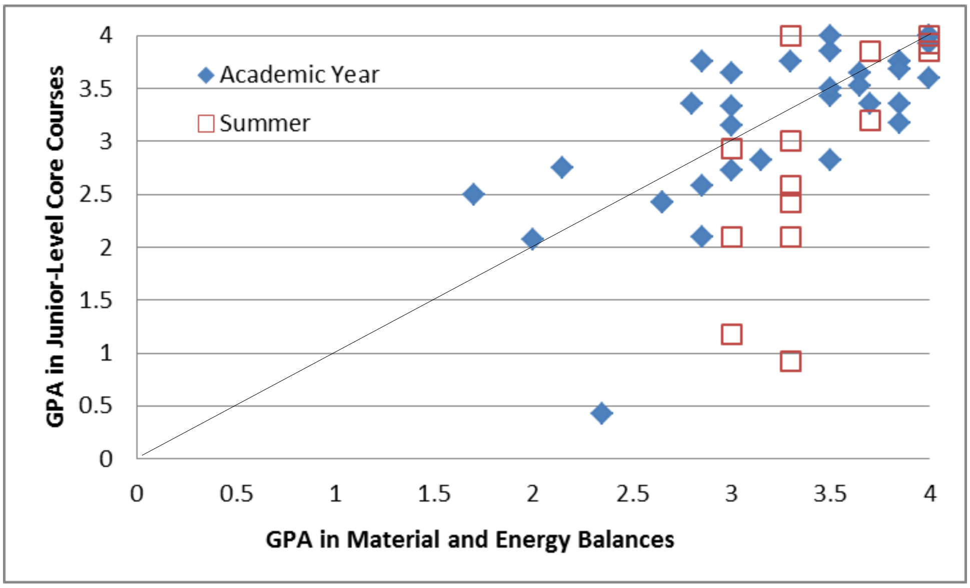

Figure 1: Cumulative GPA in four junior-level core ChE courses versus GPA in the material and energy balances course (PCP) for summer cohort, or courses (PCP I and II) for academic-year cohort.

Table 2: Linear regression parameters for the data shown in Figure 1.

Cohort	Slope	Y-Intercept	R^2
Summer (n=14)	1.96	-3.894	0.493
Academic Year (n=34)	0.864	0.389	0.519
Both Combined (n=48)	0.934	0.0092	0.391

In summary, the data show that the academic-year cohort earned significantly higher grades on average than the summer cohort. Further, only 11 out of 14 (79 %) of the summer cohort students remain on a 4-year path to graduation in ChE, compared to 31 out of 34 (91 %) of the academic-year cohort. The most straightforward explanation for these differences is that the roughly 13 month delay between the completion of PCP in the summer of 2014 and the start of the fall 2015 semester was disadvantageous to the students, at least in some cases.

However, the authors recognize other differences between the summer PCP course and the academic year offerings:

- The summer PCP course was offered online and asynchronously over an 8-week period, while PCP I and II were traditional classroom courses, each meeting twice per week for 14 weeks.
- All assignments in the summer PCP course were individual, while PCP I and II had team homework assignments, and PCP II included a team project that encompassed both material and energy balances.
- The summer PCP course was taught in a single section, while PCP I and II were taught in two sections each. These five course sections had five different instructors.

Consequently, the authors also conducted a more detailed evaluation of student exams for both cohorts in order to benchmark student achievement of course instructional objectives using a common standard. This is described in the next section.

Assessment of Student Work Product

Course grades have several limitations for use as the sole metric for student mastery of the course material.[8] One is that classes taught in multiple sections in different semesters do not necessarily have uniform expectations across sections. Another is the fact that a grade is a single holistic measure of success in a spectrum of activities, and consequently cannot be used as a metric for mastery of *specific* principles or competencies.[8] Consequently, as a more detailed and more uniform metric for student achievement of learning objectives, student exams from both cohorts were evaluated by a common reviewer using a common set of rubrics. The rubrics were devised to be applicable to a broad range of PCP problems, and were designed to focus on problem-solving abilities that are essential in the four junior-level core ChE courses. The rubrics included:

- Conceptualization and parameterization of a system or process;
- Application and simplification of material balances;
- Application and simplification of energy balances;
- Quantifying inter-relationships between physical properties; and
- Application of principles of equilibrium to multi-phase systems.

The complete rubrics are shown in Table 3. These rubrics and their use were also described in a previous publication.[9]

Table 3: Rubric used in evaluating student exam submissions

	4	3	2	1
Conceptualization and Parameterization	Thorough and accurate interpretation of problem statement. Correctly identifies all knowns and unknowns.	Broadly accurate interpretation of problem statement but misses a subtle point.	Correctly interprets many aspects of problem statement but makes a major conceptual error, or multiple minor errors.	Fundamental misunderstanding of system or process described in problem statement.
Material Balances	Writes accurate material balance equations, correctly identifies terms that are 0 or negligible for case, and accurately relates remaining terms to system parameters.	Writes accurate balance equations, but makes a minor error in simplifying the equation or relating a term to system parameters.	Shows some ability to apply material balance, but makes a major conceptual error, or multiple minor errors.	Fails to apply material balances in an accurate or meaningful way.
Energy Balances	Writes accurate energy balance equations, correctly identifies terms that are 0 or negligible for case, and accurately relates remaining terms to system parameters.	Writes accurate energy balance equations, but makes a minor error in simplifying the equation or relating a term to system parameters.	Shows some ability to apply energy balance, but makes a major conceptual error, or multiple minor errors.	Fails to apply energy balances in an accurate or meaningful way.
Physical Properties	Thoroughly and accurately quantifies relationships between the physical properties of a phase (e.g., equations of state, molar-mass conversions etc.)	Generally accurate in quantifying physical property relationships but makes a subtle or minor error.	Recognizes relevant physical principles but makes a major conceptual error, or multiple minor errors.	Fails to recognize, or fundamentally misunderstands, relationships between physical properties.
Phase Equilibrium	Displays a thorough recognition of the meaning of equilibrium and accurately applies equilibrium principles and models to the system.	Generally accurate application of equilibrium principles and relevant models, but makes a subtle or minor error.	Attempts to apply principle of equilibrium and relevant models, but makes a major conceptual error, or multiple minor errors.	Fails to apply the principle of equilibrium in a meaningful or accurate way.

The authors collected all of the exams from PCP II for the students in the academic-year cohort and PCP for the students in the summer cohort. The evaluator was not the instructor for any of these course sections. In total, there were eight problems for the academic-year cohort (4 exams with 2 problems each) and 11 problems for the summer cohort (3 exams with 3, 3 and 5 problems, respectively). The evaluator examined each problem from each exam, and made a determination about which of the five aspects were applicable to the problem. For example, "Conceptualization and Parameterization" was applicable to every problem, while "Phase equilibrium" was only applicable for problems that involved either vapor-liquid or liquid-liquid equilibrium. The evaluator then read each student's solution to each problem and assigned a rating for each applicable category. Table 4 shows the average of all data points collected in each of the five categories.

Based on the mean ratings for all students and all problems, the summer cohort scored better in four out of five categories, with the academic-year cohort, on average, scoring better with respect to energy balances. The only statistically significant difference between the two cohorts at 95 % confidence was in the data for "phase equilibrium," with $p < 0.001$ in this case.

Overall, this data suggests that the summer cohort's mastery of the course objectives *at the time they were taking the course* was at least as good as the academic-year cohort's. This data strengthens the conclusion that the difference in performance between the two cohorts in the junior-level core courses is attributable to a difference in retention, rather than to differences in the achievement of learning outcomes during the mass and energy balances course itself.

Table 4: Mean performances of two cohorts with respect to five aspects of problem solutions, measured for PCP II exams for the academic-year cohort and PCP exams for the summer cohort.

	Summer Cohort	Academic Year Cohort
Conceptualization/Parameterization	3.69	3.56
Material Balances	3.71	3.59
Energy Balances	3.19	3.32
Physical Properties	3.23	3.03
Phase Equilibrium	3.74	3.24

Summary and Conclusion

This study compared the performances of two cohorts of chemical engineering students at Rowan University. One cohort took material and energy balances as a single 4-credit course in the summer of 2014. The other cohort took material and energy balances as two 2-credit courses during the 2014/2015 academic year. Both cohorts were enrolled simultaneously in four junior-level core chemical engineering courses in the fall of 2015. Student mastery of material and energy balances was quantified using both course grades and a common set of assessment rubrics applied to student exams by a common evaluator. The data collected using both of these metrics indicates that the summer cohort's mastery of material and energy balances at the time they were taking the course was at least as good as the academic-year cohort's at the time they were taking the second course in the sequence. However, the academic-year cohort, on average, earned significantly higher grades in the junior-level core chemical engineering courses. The difference in junior-level core course performance is therefore attributed to superior retention of the course material by the academic-year cohort.

The difference in retention is most likely attributable to the fact that the summer cohort experienced a much longer time delay between completion of the material and energy balances course and the junior-level core chemical engineering courses that build upon it. It is also possible that differences in the method of course delivery led to differences in retention; for examples, the spring 2015 course included a project which the summer 2014 course did not, and the spring 2015 course was delivered in a traditional classroom setting, while the summer 2014 course was delivered in an online, asynchronous setting.

All chemical engineering students at Rowan University are assigned a faculty adviser. The results of this study have been disseminated to the faculty and will be used to inform future student advising and decisions made during the registration process.

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