A Two Course Introductory Sequence for Chemical and Life Science Engineering
Kendra W. Brinkley¹, Rosalyn Hobson Hargraves², Rudy Krack³

Abstract – Many chemical engineering students recall the feeling of being propelled into the curriculum without the appropriate analytical skills to successfully navigate through the courses. Many schools have implemented freshman engineering courses to serve as an introduction to the engineering field and basic engineering concepts. While retention rates have improved significantly, there is still much more to be accomplished if we are to meet society’s demand for engineering professionals. In the 2010-11 academic year, Virginia Commonwealth University launched a two course, introductory chemical engineering sequence to prepare students for the more rigorous, sophomore chemical engineering courses. The students needed freshmen engineering courses that would not only solidify their interest in a career in chemical engineering, but also provide a solid foundation in fundamental chemical engineering principles. Reflective interviews from these students, now in their senior year, revealed a sense of readiness among students, after taking the two course sequence.

Keywords: chemical engineering, introduction to engineering, retention

INTRODUCTION

The chemical engineering profession has evolved over the decades. A discipline that had its origins in the petrochemical and heavy chemical industries has now expanded into industries as disparate as pharmaceuticals to cybernetics, food to electronics, and healthcare to space exploration. As the world and technologies evolve, the role that chemical engineers play in industrial settings evolves as well. Their specialized skill sets must expand to include more than traditional process engineering. As educators, we must ask “Are we training chemical engineers who possess the skills that span the various roles they may play in industry?” and “Are we producing enough engineers to fill these roles?”

The average chemical engineering class reduces by at least 40% before the fourth year at many institutions. [1] [2] A number of both current and former engineering students attribute this decrease to a variety of factors including an unclear understanding of chemical engineering, early failures in freshmen gateway and sophomore engineering courses, or the inability to work collaboratively with peers. [3] Many institutions currently have freshmen engineering courses that serve as an introduction to general principles of engineering to help to solidify students’ interest in the field. However, based upon student performance and attrition, we have deduced that further development and expansion of these introductory courses will assist students in successfully maneuvering through the chemical engineering curriculum and developing critical thinking and problem solving skills which are required in industry. [2] [3] This study focuses on Virginia Commonwealth University’s development of such a sequence and its effect on students’ attitudes towards the chemical engineering curriculum and profession and success in subsequent engineering courses.

Prior to the fall semester of 2010, Virginia Commonwealth University chemical and life science engineering students enrolled in their first engineering course in the fall semester of their freshman year. This introductory

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engineering course (CLSE 101) served as a platform to expose students to concepts and a way of thinking that may have been lacking in their prior education. The curriculum focused primarily on unit conversions, algebraic problems, and an introduction to the field of chemical engineering. The use of problem sets and limited experiments drove the learning process. Students did not enroll in subsequent chemical engineering courses - CLSE 201 Chemical Engineering Fundamentals I - Material Balances and CLSE 215 Introduction to Programming for Chemical and Life Science Engineering until the fall semester of their sophomore year. In these courses, traditional lectures and problem sets were the primary pedagogical technique employed. The sophomore course instructors noted that students seemed to have too large a gap between their introductory course and their first in-depth engineering course. A significant amount of time was spent providing students with detailed background information and reinforcing concepts that were covered in the introductory course, leaving little time to focus on new material. Thus, in order to maintain continuity of learning in the specialty, a two course sequence was developed for freshmen chemical engineering students, Introduction to Chemical and Life Science Engineering (CLSE 101), a three credit course, and Methods in Chemical and Life Science Engineering (CLSE 102), a one credit course. In addition, the three credit programming course, Introduction to Programming for Chemical and Life Science Engineering (CLSE 115), previously taught by Computer Science faculty in the fall term of sophomore year, was moved to the spring term of freshman year, and changed instructors to CLSE faculty.

The literature notes that active learning environments have made a considerable impact on student’s ability to retain and process information. [4] This is further strengthened by continuous repetition in presentation of the material. These theories were used when determining the pedagogy used to convey the content for these two introductory classes. The course objectives and curriculum were selected to narrow the gap in chemical engineering student’s education.

The first offering of the CLSE 101/CLSE 102 occurred during the 2010-2011 academic year. These courses would serve as an active learning platform for the chemical engineering education. The curriculum also focused on giving students exposure to material that will be covered in higher level engineering courses.

**COURSE DESCRIPTIONS**

During the first year the CLSE101 - CLSE 102 sequence was offered, 43 students completed both courses. All students intended to pursue a bachelor’s of science degree in chemical and life science engineering. All students enrolled in CLSE 102 had to successfully complete the CLSE 101 course with a grade of C or better. Students in CLSE 102 also had to be simultaneously enrolled in an engineering programming course (CLSE 215). These prerequisite and co-requisites were intended to ensure that the students were exposed to the same material and possessed the skills necessary to successfully complete upper level courses.

**Introduction to Chemical and Life Science Engineering (CLSE 101)**

The goal of the Introduction to Chemical and Life Science Engineering course is to introduce students to the field of chemical engineering, the Chemical and Life Science Engineering (CLSE) Department, and chemical engineering fundamental principles. The course covers basic concepts related to units, problem solving, the engineering approach, and process variables within the context of chemical engineering examples or hands-on projects. Students learn about the different careers in chemical engineering. Students are given assignments that develop their communication skills and problem solving skills. They are given team projects in which they learn about and apply the engineering design process. Fundamental chemical engineering principles are covered including units and unit conversions, data representation and processes, and process variables.

Traditional methods are used to assess the students including homework, tests, and quizzes. Students are assigned homework weekly and complete periodic in-class pop and announced quizzes. While homework can be a collaborative effort, quizzes reflect individual student knowledge. Three tests account for 30% of the student’s grade allowing for assessment of individual student mastery of the fundamental principles covered in the class. Class participation and attendance are also factored in when determining their final grade (10%). However the largest portion of their grade is determined by their team projects.

**Methods in Chemical and Life Science Engineering (CLSE 102)**

The goal of the Methods in Chemical and Life Science Engineering course is to teach students how to identify and formulate chemical and life science engineering problems. Students are shown different real-world scenarios and applications. Emphasis is placed on how concepts from mathematics, chemistry, and biology can be applied to real-
world scenarios to arrive at solutions through the application of an engineering approach. Heavy emphasis is placed on developing academic integrity, enhancing inductive/deductive reasoning for problem solving, and strengthening the understanding of the impact of self-efficacy and culture on their problem solving approaches.

Students were challenged weekly with various activities that facilitated peer interaction and could also be applied to industrial situations. Topics including translating word problems into mathematical equations, mass transfer techniques, unit analysis, heat transfer, reaction engineering, mass balances, energy balances, and fluid dynamics were covered during the course. Because a wide variety of topics were being covered, only one was introduced in-depth: mass balances. However, a general overview was given for the remaining topics.

During the semester, students were responsible for working in teams to complete two design projects. These projects incorporated real life scenarios that both traditional and non-traditional chemical engineering professionals may encounter. These activities required the use of math, chemistry, biology, and engineering concepts to evaluate and solve the scenario. Students were expected to attend the course once a week to present their solutions to problem sets, as well as attend lectures for fundamental information.

During the 2010/2011 academic year, heavy emphasis was placed on the material balance and the problem solving procedure portion of the course, while other topics were only briefly introduced. Class sessions were divided into three parts: review, lecture, and evaluation. Ten minutes were dedicated to an in class review of the previous week's lecture, through a one question quiz. A 30 minute lecture followed the quiz and any outstanding questions that students may have. Lastly, students were given 10 minutes to ask any pressing questions.

Homework assignments were given out each week. These assignments were a mixture of calculations, written reports, data analysis and interpretation. Though students were allowed to work with their peers each student was responsible for turning individual assignments and explicitly state any collaborative efforts that were used in completion of the assignments. Homework and quizzes were worth 20% of the student’s grade. While the other 80% were composed of the class project, a midterm report, and test.

During the lecture portion of class sessions the lecturer continually stressed a systematic approach to solving word problems. The problem solving approach called for students not only to have the ability to identify pertinent information, but also use both inductive and deductive reasoning skills to develop mathematical expressions to solve such problems. The steps to the approach are described in Figure 1. Students were expected to use this process when assignments.

The end of semester project was designed to allow students to apply their new knowledge to real world scenarios. The project was also used to illustrate how the same basic chemical engineering concepts and problem solving techniques may be applied to promoting collaboration amongst peers and to refine the writing skills. Table 1 outlines the principles that are covered in the end of semester.

![Figure 1 – Problem solving methodology](image-url)

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The first portion of the project described a gas chromatography separation technique. Students were responsible for identifying the contents in each separation stream. They were also asked to comment on both environmental and industrial constraints that may limit the extraction of such materials. Finally, students were asked to develop possible solutions and implantations procedures to make the constraints minute to separation process. The second portion of the project asked students to evaluate the process to recover crystalline potassium chromate. Students evaluated the efficiency of the recovery process and the implications of such a process. In both portions of the project students revisited engineering topics including: mass balances, process efficiency, mole and mass percent, and basic problem solving techniques.

### Table 1

*Semester Project Chemical Engineering Principles.*

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<table>
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<tbody>
<tr>
<td>1.</td>
<td>Material Balances</td>
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<td>a.</td>
<td>Formal definition of mass and mole fractions and percentages</td>
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<td>b.</td>
<td>Introduction to material balance equation</td>
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<td>[ Accumulation = Input - Output + Generation - Consumption ]</td>
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<td>c.</td>
<td>Formal Definition of steady state processes</td>
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<td>2.</td>
<td>Engineering Design</td>
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<td>a.</td>
<td>The effect of environmental factors</td>
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<td>b.</td>
<td>The effect of financial constraints</td>
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<td>c.</td>
<td>An introduction to engineering process equipment</td>
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**Introduction to Chemical and Life Science Engineering CLSE 101 Course Objectives**

Upon successful completion of this course, students should be able to:

1. Describe the diverse roles of chemical engineers
2. Apply significant figures and units to calculations
3. Apply problem solving and design approach skills
4. Understand and label processes and process variables

**ABET Program Outcomes Addressed in CLSE 101**

(d) an ability to function on multi-disciplinary teams  
(f) an understanding of professional and ethical responsibility  
(i) a recognition of the need for, and ability to engage in life-long learning  
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context  
(j) a knowledge of contemporary issues

**Methods in Chemical and Life Science Engineering CLSE 102 Course Objectives**

Upon successful completion of this course, students should be able to:

1. Identify chemical and life science engineering problems in everyday life settings;  
2. Formulate an engineering problem given a problem statement;  
3. Understand the contributions of mathematics, chemistry, and biology to solving Chemical and Life Science Engineering problems.

**ABET Program Outcomes Addressed in CLSE 102**

(a) an ability to apply a knowledge of mathematics, engineering, physics, chemistry, and biology.  
(e) an ability to identify, formulate, and solve chemical and life science engineering problems.  
(g) an ability to communicate effectively.

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**IMPACT DATA COLLECTION**

Based on the review of the literature, an interview protocol [5] was developed for this study. The students were interviewed individually in 30 minute sessions, starting with a brief introductory conversation to introduce goals of

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the study to participants. All students who enrolled in and completed the first offering of CLSE 102 were invited to participate in the interviews. No incentives were given to encourage students to participate. Five students who were part of the first chemical engineering 102 course were interviewed. Informed consent, according to the Institutional Review Board procedures of Virginia Commonwealth University, was conducted at the beginning of the interview session. At that meeting, the researchers reviewed the purpose of the study, answered any questions a participant had, and gathered any demographic data that was available. These steps are part of the approach that Seidman [5] recommends to build a rapport and establish a researcher-study participant relationship necessary for in-depth interviewing.

The interview explored participants’ perspectives about the CLSE 102 course, the impact of the course on their decision to remain in or leave the major, and the student’s preparedness to progress through the chemical engineering curriculum. The questions also investigated whether the course promoted interaction with their peers. Furthermore, these questions were used to evaluate the effectiveness of the actual course meeting its objectives as previously listed. Questions were open-ended and exploratory, allowing the participant significant freedom to describe his/her experience in a manner that does not direct or constrain the perspective he/she provides. Students were also given the opportunity to offer any information they deemed pertinent that was not covered during their interview session. The interview protocol questions are displayed in Table 2.

<table>
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<th>Table 2. Interview Questions</th>
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<td>1. Did the 102 course assist in retaining and understanding information for your future engineering courses? If so, how?</td>
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<td>2. If you had not taken this course do you think your academic career in chemical engineering would have been adversely affected? How so?</td>
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<td>3. Did the course assist in your decision to stay or leave the chemical engineering curriculum?</td>
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<td>4. Did this course promote interaction with your peers?</td>
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<td>5. Should the 102 be a requirement for future engineering students?</td>
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<td>6. Did you feel ready for your next engineering course after taking both the 101 and 102 engineering courses?</td>
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**DATA ANALYSIS**

Five students of diverse race, ethnicity, and background were interviewed. While this sample is very small and far from representative, it has presented some interesting results in the early stages and provided the researchers with an interview protocol and data analysis process which the researchers will use to inform a larger study. Following Creswell’s [6] description of the systematic process of data analysis in grounded theory the researchers met to review the interview transcripts and develop, sort, compare, and contrast codes and categories until no new codes were created. Based upon that qualitative analysis of the study data, the researchers identified the following codes and categories given in Table 3.

<table>
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<th>Table 3. Data Coding</th>
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<tr>
<td><strong>Primary Code</strong></td>
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<td><strong>Academic Preparation for CLSE</strong></td>
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<td><strong>Interaction with peers</strong></td>
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<td><strong>Retention</strong></td>
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Excerpts from individual interviews were selected based on the researcher’s discretion. In that regard, when the students were asked if the 102 course assisted them in retaining and understanding information for their future engineering courses, 3 out of five students reported that the course did help with their understanding of the material in mass and energy balances. One student recounted a sense of satisfaction as the instructor from another energy course introduced new material.

“Even though I didn’t know everything, I knew why we were approaching the problems like this. I guess that made it easy because I knew why instead of just trying to memorize equations.”

Of the two students that reported that this course did not help them understand the material, one completely left the chemical engineering program to pursue a degree in chemistry, while the other student reported to have an extensive background of what to expect in the higher level courses because a close relative recently matriculated through the curriculum. The data and the excerpt suggest that those who took this course had the opportunity to gain a deeper understanding of course material. It also suggests that concepts in both the 102 course and the higher level course were closely related and students were able to benefit from previous experiences.

In analyzing the second question, 80% of the students reported that not taking this course could have adversely affected their academic career. One student reported, after quitting the chemical engineering curriculum, that if he had not taken the course they may not have discovered that chemical engineering was not for them. Alternatively he would have been stuck in a discipline that did not interest him, and was too challenging for him. Other students suggested that because the same themes and topics were covered in the introductory course as in higher level engineering courses they were able to better understand the practical uses of the material and thus were able to logically solve example problems in a classroom setting.

Despite the apparent impact the introductory course sequence offered, 80% of the students reported that the 102 course did not assist in their decision to stay or leave the chemical engineering curriculum. A number of students did not believe that such a decision could be influenced by the brief exposure.

“I think we knew just enough at the time to carry us through the next course but we still solved the simplest form of chemical engineering problems. We would have to wait until we knew more to make that type of decision.”

“The course was a great introduction to chemical engineering from the type of work, to what teachers expected, but it was just an introduction, we still had to go through more before deciding whether to stay in the curriculum or not.”

The single student who withdrew from the engineering curriculum described the course, as an eye opener.

“Though this was not my deciding factor I started to really think ‘Is this what I really want to do for a job or, is this even the major for me?’ I decided to take courses for my chemistry major just in case during the next class I would figure out this wasn’t for me.”

Despite the limited depth of knowledge that the students gained from the two introductory courses, 80% of the students questioned felt that they were prepared for higher level courses, as illustrated by one subject, who said:

“Engineering is a different way of thinking that I really didn’t have to do in high school. I wasn’t used to really understanding why I was doing something and I wasn’t used to failure. If nothing else, I learned what to do when I didn’t get something initially. Failure is only failure if you let it get you down. I wasn’t going through it by myself because we all helped each other, not just the “smart” people in class but everybody, and we still do. So that was the big factor, knowing there was support from others I could also lean on.”

Each student of the program seemed to share the same sentiments shown in the above excerpt and this was especially evident in the evaluation of the fourth question regarding the promotion of interaction with peers. All of the interviewees expressed that this course continually encouraged collaboration with their classmates. As captured in previous quotes, not only was there collaboration between students; but, they began to build support networks for one another.

All of the students interviewed believed that this two course series should be permanent in the chemical engineering curriculum. A number of students noted there are several changes that may be made to make this a more enriching course. The students thought this should be a course that met at least two if not three times weekly. Secondly, the
The future of this course is largely dependent on curriculum developers who seemed to progress through the academic career. Students believed that the topics could be narrowed down to going in depth about fewer topics. Finally, the course could be solely scenario based with less time spent in reviewing basic topics.

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<th>Table 4 – Percentage of students who earned a grade of D, F, or W in the Fall Semester Sophomore Chemical Engineering Course</th>
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To quantify the impact of the two course series on students’ performance, the percentage of students who earned a grade of D or F or withdrew from the course (D,F,W rate) were examined for the sophomore level fall semester engineering course for both the students who participated in the two course series and those who did not. Not all students who participated in the pilot series enrolled in the subsequent course the following semester. The semester after the first series was launched, 23 students were enrolled in the sophomore level engineering course, CLSE 201. Of those students 17.4% received a grade of D, F, or W in the course. The following year the percentage of students who received a grade of D, F, W in the course varied little from the first year at 17.8%. This rate shows a dramatic decrease from the three prior years when only one introductory course was required of the students. In 2009, 2010, and 2011 the sophomore course D,F,W rate exceeded 40%. Dramatically decreased, exceeding 30%, from the previous two years when only a single introductory course was implemented. Specific data is shown in table 4.

While former and current instructors note that a number of factors may contribute to such a dramatic decrease, none dispute that the two course series is one of the main contributing factors. The instructors, who have taught the CLSE 101 and higher level courses, also suggest that students seem to be more acclimated to the “way of thinking” and rigourous course load that engineering students traditionally take a exceptionally long time to become accustomed to.

**SUGGESTED IMPROVEMENTS**

Students and course developers have identified the areas of improvement for the two course series. During the first year of this course developers strived to build strong connections between the CLSE 101, 102, and the material balance course during the sophomore year. However, little connection was drawn between the series and the programming course that students are enrolled during the same academic year. Students believed that the integration of programming in the series will also increase their ability to use it in other courses. It has been noted that the use of multi-media modules improved student’s performance in course assignments. [7] For the 2012 and 2013 spring terms, the course instructors coordinated efforts, since both courses had basically the same student population. Weaknesses in specific topics identified in one course were given additional emphasis in the other course. The course instructors cross listed each other on both courses’ Blackboards to further coordinate efforts. In the 2013 spring term, both courses shared a teaching assistant, who helped course coordination. During these academic years, equation manipulation, dimensional analysis, unit conversion, table and graph creation became the focal points for this course to prepare for the material balance course.

**CONCLUSIONS**

The interview population was too small to consider the findings statistically significant; however it quickly became evident that the two course series served as a valuable bridge between the freshman year studies and the rest of the academic career. Of the 44 students who enrolled in the course 26 (59%) were retained in the major and are now in their senior year in. This is approximately a 5% increase over the VCU average. Virginia Commonwealth University students who participated in the pilot CLSE 102 course are the largest chemical engineering class to progress through the chemical engineering curriculum and graduate in four years. The active learning environment seemed to provide the students with high morale and confidence in their ability to complete the required courses. The future of this course is largely dependent on curriculum developer’s own beliefs in the significance to build...
such bridges. However, one cannot ignore the great service that it provides the students, to even at early stages of their career, allows them to take ownership and continuously build during their academic careers.

REFERENCES


AUTHORS

Mrs. Kendra Brinkley

Mrs. Brinkley received a Bachelor’s of Science in Chemical Engineering from the University of Virginia in May 2009. In August of the same year she joined Virginia Commonwealth University (VCU) seeking a Ph.D. in Chemical and Life Science Engineering. She was awarded an Outstanding Teaching Assistant Award for her dedication during TA assignments, and a GANN fellowship. She earned her master’s degree in the fall semester of 2011 and intends on completing her Ph.D. in December of 2014. Kendra is as dedicated to research as she is to education. As a doctoral student, she developed and taught a new Chemical and Life Science Engineering (CLSE) course for VCU freshmen CLSE majors. She also taught a summer chemistry class for the VCU Summer Transition Program which is an NSF funded preparatory program for incoming underrepresented minority STEM majors.

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