AC 2012-3770: INTEGRATING SUPPLEMENTAL INSTRUCTION INTO FRESHMAN CHEMISTRY PROGRAMS TO SUPPORT WOMEN IN ENGINEERING

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Integrating Supplemental Instruction into a Freshman Chemistry Course to Support Women in Engineering

Abstract

The Connections Chemistry Review was developed at Northeastern University as part of a series of programs initially funded by the National Science Foundation to address the importance of success in introductory science and math courses for first-year engineering students. This program has provided supplemental instruction for General Chemistry for Engineers (CHEM 1151), a common required course in which freshmen have historically struggled during their first semester in the College of Engineering. In order to retain the interest of first-year women majoring in engineering and provide role models in this historically male-dominated field of study, review leaders have been selected from upper-class women majoring in chemical engineering. Recently, the Connections Chemistry Review was revamped to introduce several key features designed to increase student participation and success. These features include requiring review leaders to attend lectures, developing review sheets, holding review sessions in the early evening in a freshman residence hall, heavily advertising sessions, offering free pizza to motivate students to participate, and making concerted efforts to identify and assist struggling students with additional one-on-one tutoring. In addition, the course coordinator is incorporated into the program to promote further student participation and assure smooth integration and coupling of supplemental instruction with other facets of the course. With this redesign, the Connections Chemistry Review was made available to all students (male and female) taking CHEM 1151. Based on the results from pre- and post-surveys for freshmen enrolled in this first-year chemistry course during the Fall 2011 semester, we found that students with weaker backgrounds in high-school chemistry were more likely to attend supplemental instruction provided by upper-class female tutors, students who felt less comfortable in their previous preparation were more likely to benefit from this program, and that female students were more likely to participate than male students.

Background

Women currently are underrepresented in the numbers of students enrolled in Science, Technology, Engineering, Math (STEM) majors as well as obtaining engineering degrees and employment positions.[1] Although women represent nearly 50% of the workforce in the US, they currently fill less than 25% of STEM positions[3] and hold less than 11% of engineering positions.[2] The problem is further compounded by the fact that women hold a significantly lower proportion of leadership positions in STEM than their male counterparts.[4]

Increasing the enrollment, retention, and graduation rate of women in engineering is essential for US global competitiveness and future economic success, as a diverse pool of individuals will be advantageous in solving domestic and global technical problems.[5] Several barriers continue to limit participation by women in engineering studies, including discrimination, unwelcoming university attitudes, and a lack of role models.[4] Simply overcoming enrollment barriers is insufficient, for a significant percent of women who do choose to enroll in these programs do not complete their degrees. Self-confidence has been shown to be an extremely important factor in enabling women to complete degrees in engineering.[6] In 2010, 40% of females in chemical engineering positions reported feeling discouraged at some point during their career, with US

colleges the primary place where discouragement is occurring.[7] Fostering a supportive engineering student body also can mean incorporating male students into programs that strive to increase female participation and success.[5]

Supplemental enrichment programs can greatly help recruit and retain women in engineering majors.[6] Such programs are part of a larger need. According to the Bayer Facts of Science Education Survey XV in 2011, 71% of those surveyed reported that additional staff is warranted to enrich the amount of academic support necessary for retaining more engineering students.[7] These programs are particularly critical given that "weeding-out" practices have been found to be harmful to young engineering students, with women and minority students more affected than their white male counterparts.[7] Such support is especially warranted during the freshman year, as significantly more students switch their majors from engineering during their first year compared to subsequent years at the undergraduate level.[8] Studies have found that enhanced self-efficacy and social support in the first year experience can lead to improved adjustment and academic performance, which, in turn, shapes overall satisfaction and commitment to remain in school.[9,10,11] This effect is particularly important for women students: compared to their male counterparts, women have been reported to have lower initial academic self-efficacy.[12,13]

The program described in this paper provides another form of enrichment to improve the retention of women in engineering programs by assisting students in the successful completion of an essential course in their freshman engineering curriculum, CHEM 1151 - General Chemistry for Engineers. Northeastern University students intending to major in an engineering discipline typically take this course during the fall of their freshman year. The course meets three times a week in sections of approximately 100 students in a large lecture hall and once weekly in recitations of approximately 30 students. Lectures are taught by multiple instructors, who coordinate to cover common material that consists of both introduction of new concepts as well as one or two active-learning exercises. Students also participate in lectures using "clickers" to address questions posed by the instructor. These clickers provide both the individual student and the instructor feedback regarding understanding and retention of material while simultaneously tracking students' attendance. During recitations, teaching assistants review key concepts and help students address difficult problems in their weekly homework assignments. To provide students feedback and encourage weekly study (instead of just before exams), recitations typically include a 10-minute quiz. Students in all sections take three common 65-minute midterm examinations and one common two-hour final examination.

Outside of lecture and recitation, multiple resources are available for students seeking help in CHEM 1151. Students can attend instructor office hours or go to "Chem Central," a room staffed by chemistry professors and graduate students weekdays from 10 am-4 pm to assist all science, engineering, and nursing students taking courses in general chemistry. The College of Engineering also provides a tutoring center to all students for their freshmen year classes. However, many students do not take advantage of these resources, in part because they are only offered during the day and because they are reluctant to ask their instructors and teaching assistants for help directly.

Program

The Connections Chemistry Review meets once a week to provide students with the opportunity for additional help in their chemistry studies while simultaneously providing a facet for

interaction between freshmen and upper-class mentors. Key aspects of the program are described below.

1. Before the beginning of the fall semester, the program coordinator (the Director of Women in Engineering) recruits three upper-class women to be the Connections Chemistry Review Leaders. These students are hand-picked to ensure that they are capable of teaching the material and able to serve as both role models and mentors to freshmen. The leaders chosen either excelled in CHEM 1151 as a freshman or had an outstanding high-school preparation in chemistry. These leaders also have earned high marks in their own studies both in chemistry and overall; this experience allows the leaders to give guidance to freshmen on how best to succeed in their engineering curriculum as a whole. It is imperative that the students view this person as someone who they feel comfortable approaching. Juniors and seniors majoring in chemical engineering best fit this criterion: they are viewed simultaneously as a peer and as a student has "made it through," resulting in effective role models and mentors. Student leaders are compensated for all work through the College of Engineering.
2. The leaders, along with the program director and the course coordinator (one of the lecture instructors), meet prior to the start of the semester in order to adequately prepare and plan. In addition, meetings continue once a week for the entire semester in order to identify and remedy any issues that arise.
3. The student leaders each attend different sections of the lecture. This practice allows the leaders to be in tune with what is being covered currently in class so that they can prepare adequately for the review sessions. It also ensures that every instructor has at least one leader sitting in on their class.
4. Weekly review sessions are held in the evening by the leaders to review the material covered in the previous week's lectures. Attendees are able to ask questions pertaining to general concepts, specific details, and/or homework problems causing them difficulty. The sessions also serve to reinforce concepts for those students who may need to hear the material explained multiple times in different voices to maximize understanding.
5. The leaders provide review sheets at each review session that summarize the concepts that will be discussed in that session. The sheets contain a variety of definitions, figures, equations, and techniques for problem solving to help the students while they study concepts and attempt homework problems.
6. All leaders have access to the on-line homework system that the course uses. This access enables the leaders to see the questions assigned to students and allows the leaders to assist in guiding a student down the right path to solve each particular problem.
7. Review sessions are held in the Living Learning Community (LLC) classroom which is located inside a freshman dorm, on the freshmen side of campus. This location makes the review session more convenient because it is located as close as possible to the freshmen residence halls when compared to the other classrooms on campus.
8. Pizza is served at each review session, which can entice those students who may not have had time to eat between their last class and the start of the review session.
9. Review sessions are advertised throughout all of the freshman dorms and by the course coordinator verbally, via e-mail, and via the course website on Blackboard. In addition, lecture instructors make a point to identify the student leaders who are sitting in on each lecture in order for the students to feel comfortable approaching that leader with questions and to attend the weekly review sessions.

10. If a student still faces difficulty even after attending a few of the sessions, the leaders and course coordinator are able to point the student to other resources for additional help including professor office hours, the College of Engineering tutoring services, and Chemistry Department tutoring services.

At the beginning of the semester, the program coordinator establishes communication with Resident Assistants (RAs) in the male and female Engineering LLCs. These RAs post fliers and verbally advertise and encourage their students to attend the review sessions. Lecture instructors also point out the availability of this resource and many others during the first lecture. Because many students did not need tutoring in high school, instructors point out the usefulness of tutoring and taking advantage of extra help resources in order to succeed in the engineering curriculum. The leaders similarly communicate the importance of tutoring and extra help, while making a concerted effort to negate the negative stigma often associated with tutoring. The leaders share personal stories about instances in college when they needed extra help through either professor office hours or with a tutor in order to help the freshmen change their attitude towards tutoring.

During review sessions the leaders alternate presenting material on the review sheets and answering questions so that each leader is engaged in the session and making connections with the students. Because the leaders are very knowledgeable in general chemistry, they often share personal tips that help them remember certain concepts or unique mnemonics that can help students remember the material. In addition, each leader offers personal advice on how to succeed during the freshman year and insight on what will come in the future. These stories often help the freshmen relate to the leaders and view them as a peer. This relationship allows the students to be more comfortable with the leaders and, therefore, more willing to ask certain questions that they may not ask a professor or advisor due to intimidation or fear of embarrassment.

Although the Connections Chemistry Review was initiated several years ago, up until this past year attention has been focused primarily on running the program and helping individual students rather than assessing quantitatively the overall and broader impact on student retention. In order to gain explicit feedback on the impact of the Connections Chemistry Review, surveys were conducted at the start and end of the Fall 2011 semester. Both the pre- and post-surveys were administered in recitations, the pre-survey during the first recitation and the post-survey during the last recitation. The pre-survey focused on demographic information and included some open-ended questions about student's previous high school experiences in chemistry and what they hoped to gain out of taking CHEM 1151. Other questions solicited the students' sentiments about chemistry and its perceived importance to engineers. The pre-survey concluded with questions asking students to rank their comfortable level on a set specific concepts that would be discussed throughout the semester in order to gain an understanding of how confident the student was in chemistry before taking CHEM 1151. The post-survey asked some of the same questions about the students' opinions of chemistry as well as had a section devoted to identifying any extra help resources that they had or had not used. The same knowledge survey from the pre-survey was included in the post-survey to determine how well the student learned the material presented in CHEM 1151. The post-survey concluded with a question about how well the students scored on their three midterm exams. All students 18 years or older were invited to participate in these surveys, regardless of whether they attended any of the

Connections Chemistry Reviews. The data from both the pre- and post-surveys were used to determine the effectiveness of the supplemental Chemistry Review program and elicit any differences in the way that men and women responded to and benefited from the program.

Results

A total of 269 students completed both the pre- and post-surveys out of a total of 470 students completing CHEM 1151 (a 55% response rate). For purposes of data analysis individual students were identified as members of one of three groups:

Group A consisted of students who did not attend any supplemental Connections Chemistry Review sessions and had an average of 80 or better on their three midterm exams (where the overall average on midterm exams was 80).

Group B consisted of students who did not attend the review sessions and had an average of 79 or less on their three midterm exams.

Group C consisted of students who attended the weekly reviews and rated them either a 4 or 5 on a 1-5 scale, meaning the review were either "useful" or "very useful," respectively. Among the 269 students surveyed 48 regularly attended the reviews and found them beneficial. The small number of students who attended a review and did not rate the reviews a 4 or 5 are included in Groups A and B.

All analyses were done on a percentage basis for comparison because the total number of students in each of the three groups varied. Statistical analysis was performed using t tests and by interpreting responses to binomial (*e.g.*, Yes/No) questions based on a binomial distribution.

When the Connections Chemistry Review program was initiated, we hypothesized that students with weaker preparation in chemistry in high school were more likely to attend review sessions. In order to test this hypothesis we compared the number of years of high school chemistry among Groups A, B, and C. Figure 1 shows that students in Group C, students who participated in the weekly reviews, had less preparation in chemistry in high school than students in Groups A and B. In particular, a student's t test showed that the higher percentage of students having had only one year of high school chemistry in Group C was statistically significant ($P > 0.99$) compared to the percentage of students in Group A. Similarly, the decreased percentage of students having taken AP Chemistry in high school observed for Group C was statistically significant ($P > 0.99$) compared to the percentage of students who took AP Chemistry in Group A. These results confirmed that the less exposure students had to chemistry prior to CHEM 1151, the more likely they were to participate in the weekly chemistry reviews.

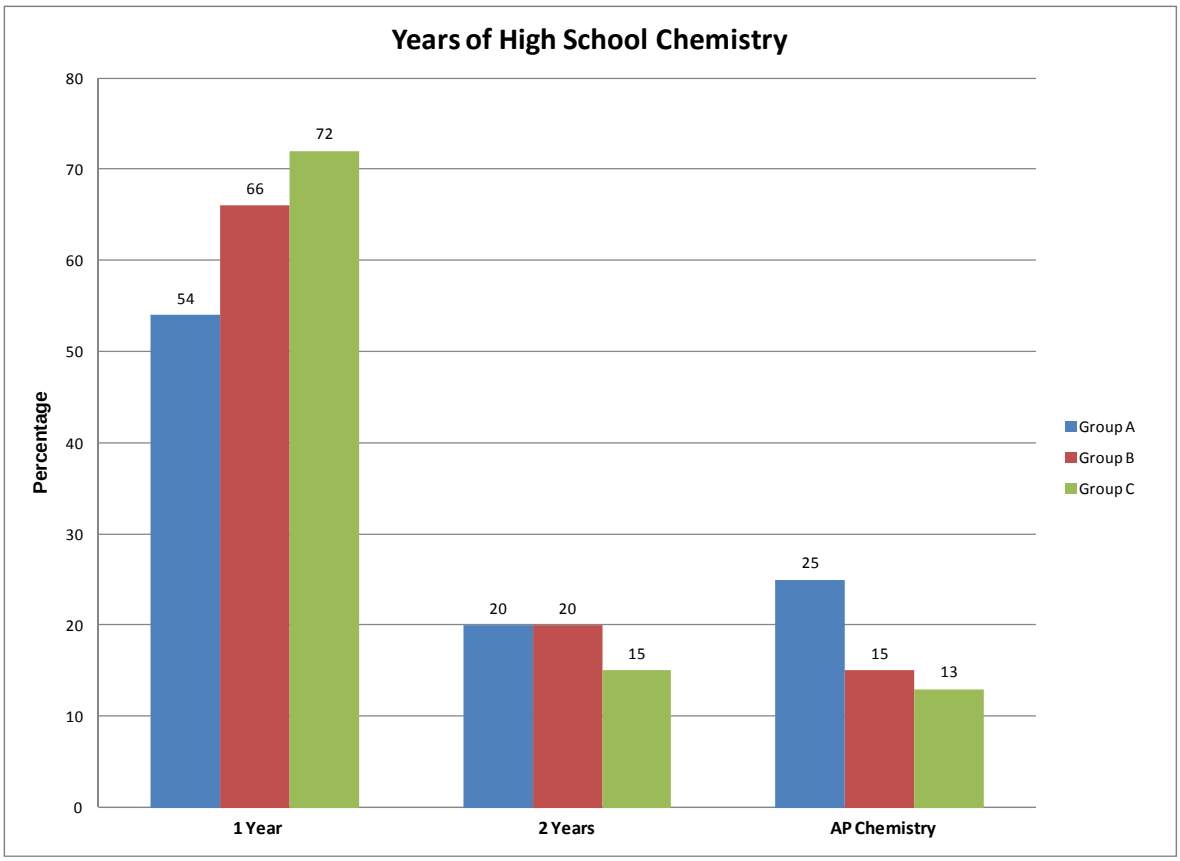

Figure 1

We had hypothesized that students who took advantage of extra help in the form of the weekly Connections Chemistry Review would have felt that they were not well prepared for CHEM 1151 prior to starting college but that, if our program was successful, would now find the subject matter not as difficult as their peers might feel. Figure 2 compares different feelings students reported about the subject of chemistry after taking CHEM 1151. Students with lower averages on midterm exams (Group B) were statistically more likely to find chemistry a difficult subject for which high school did not prepare them well than students with higher averages on midterm exams (Group A) ($P > 0.99$). The percentage of students attending the Connections Chemistry Reviews (Group C) who found chemistry to be difficult was in between Groups A and B. Although a relatively high percentage of students in Group A felt their high school chemistry course prepared them well for CHEM 1151, students in Groups B and C were split almost evenly about whether or not high school chemistry prepared them well for this course. These data show that students that feel more comfortable with chemistry prior to college did not find the subject matter of this course as challenging and did not seek as much extra help as students who did not feel as prepared.

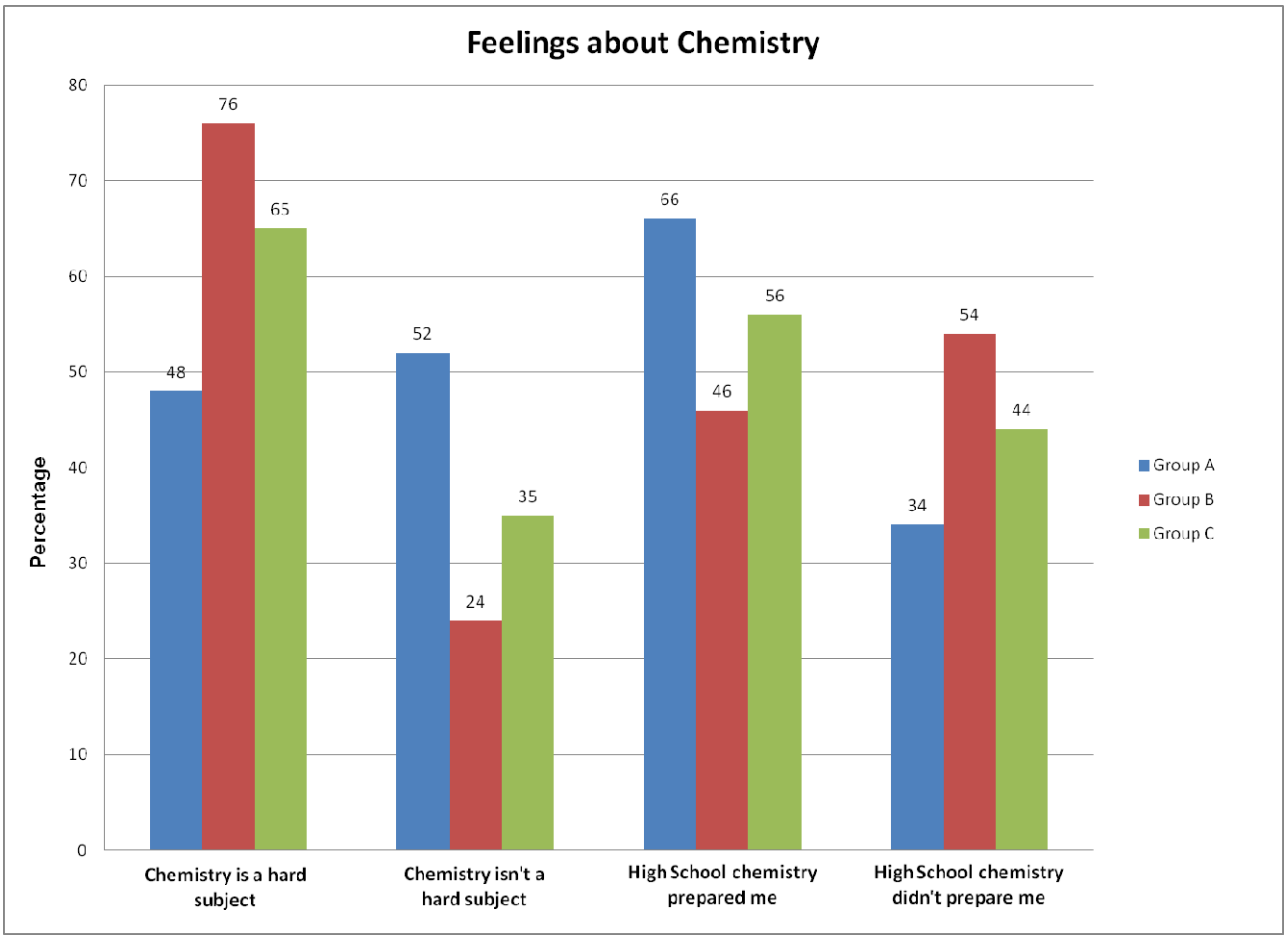

Figure 2

Figure 3 compares intended majors of students in Groups A, B and C. The largest percentage of chemical engineers was in Group A, which was expected because they tend to find chemistry the easiest and succeed in the course without extra help. Few students in Group B intended to major in chemical engineering. Review students mostly have intended majors of civil & environmental engineering, mechanical engineering, electrical engineering, and computer engineering. The largest percentage of undecided engineering or non-engineering majors was associated with students who had on average the lowest midterm grades in the course.

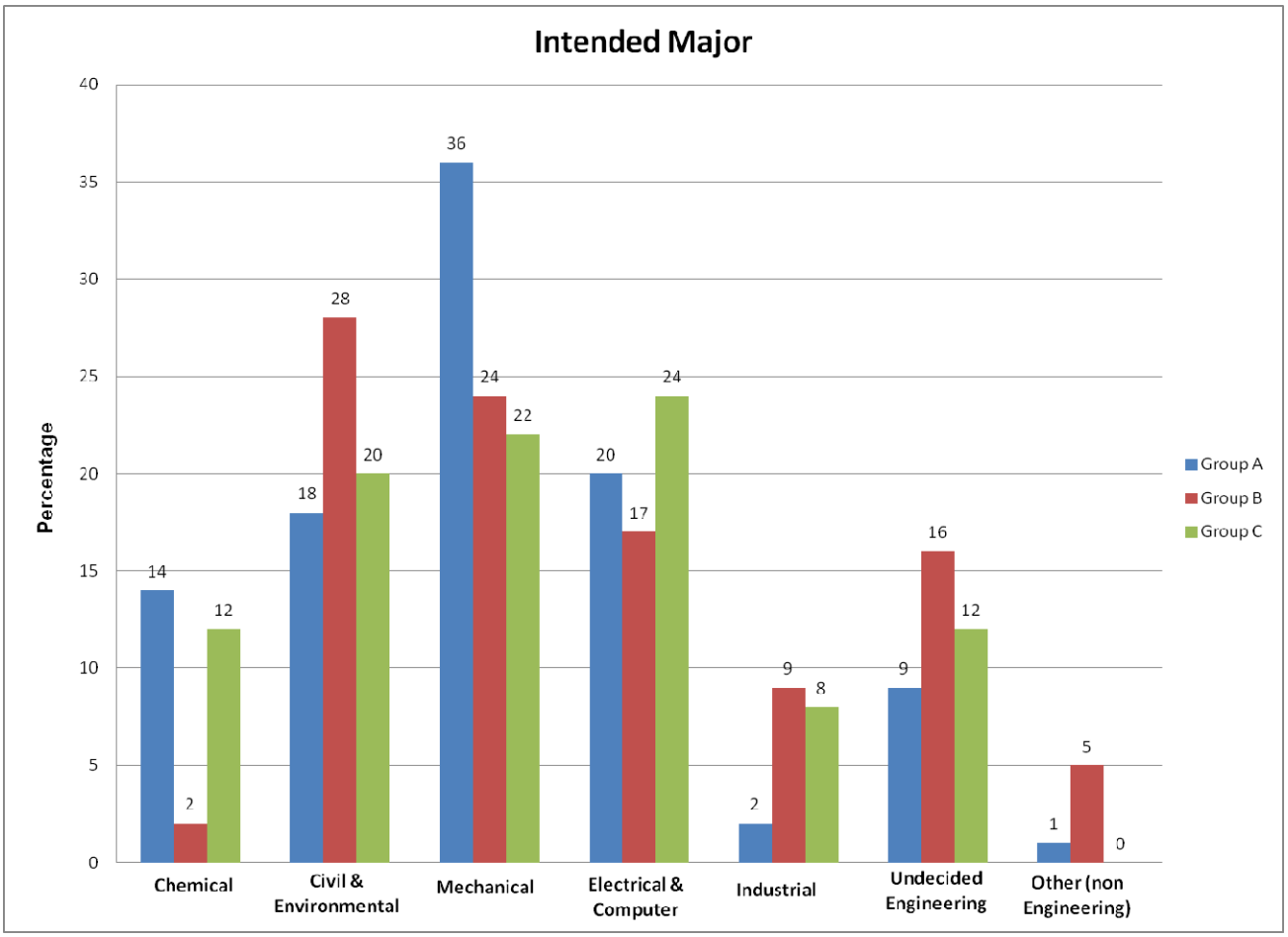

Figure 3

On both pre- and post-surveys students were asked to rank their knowledge and skills of different subtopics of chemistry on a 1-5 scale, with 1 being unfamiliar and 5 being very comfortable. CHEM 1151 had been redesigned for the Fall 2011 semester to introduce some more challenging material earlier and move balancing reactions to the middle of the semester, with the hypothesis that students would better manage the flow of new material over the course of the semester. Figure 4 shows the difference between students' knowledge and skill level before and after taking CHEM 1151 based on specific topics in the order in which they were discussed. The longer the tie lines, the larger the difference with how comfortable students were with a specific topic. We found that although students entered the semester most comfortable with topics to be discussed at the very beginning and during the middle of the semester, as we hypothesized, improvements in comfort with different topics were observed throughout the semester and that over the first approximately 80% of the semester the resulting comfort level was relatively uniform. The drop-off observed at the end of the semester can be attributed in part to student intellectual fatigue during their first semester of college and the fact that the final two topics were covered concurrently with when the post-survey was administered.

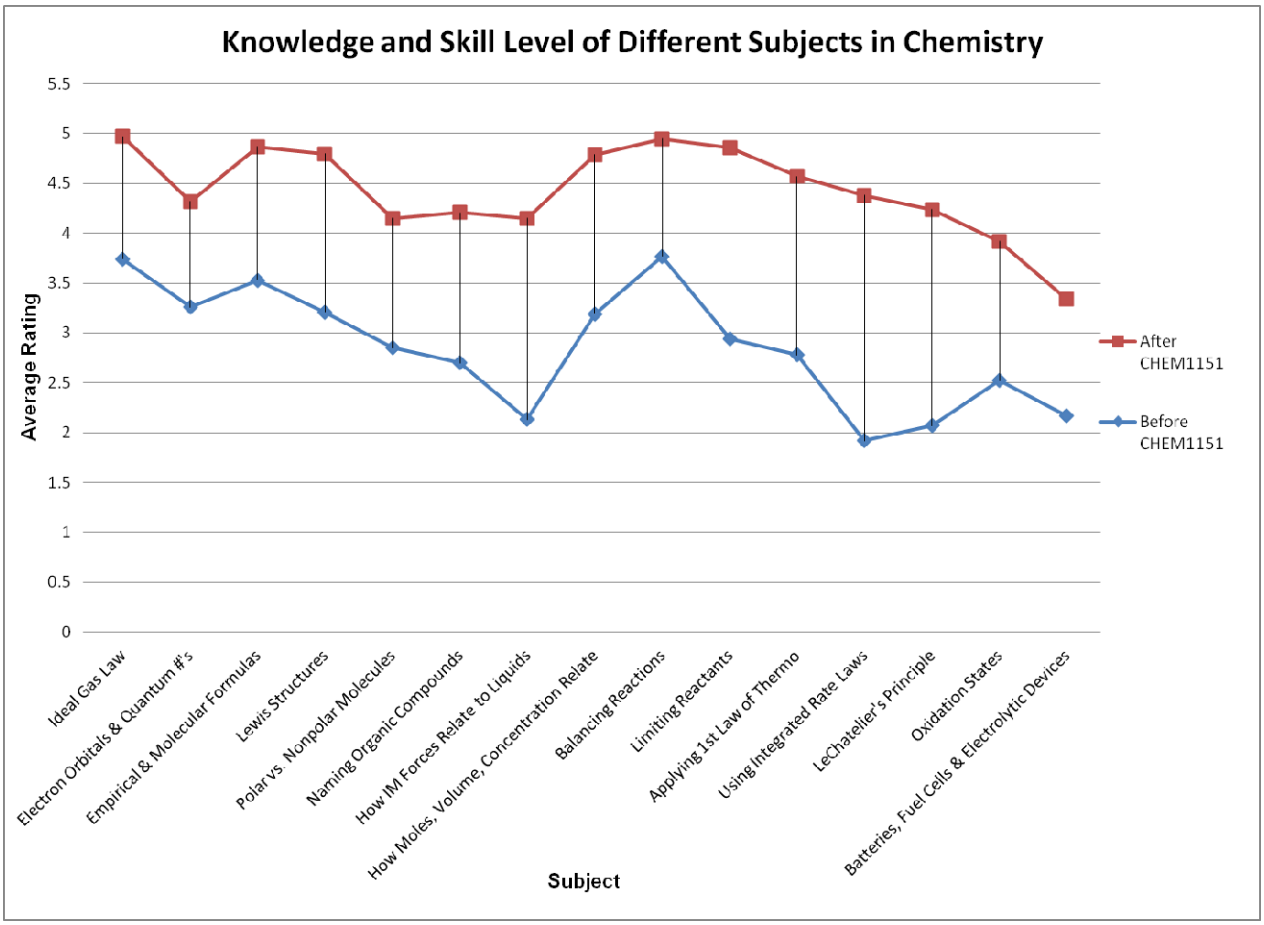

Figure 4

Overall, of the 269 students surveyed, 14% of males and 29% of females attended the weekly chemistry reviews. Although advertising for the review sessions was done partly through the Connections Program, which is a special program for Women in Engineering at Northeastern University, both men and women were welcome to attend the reviews. Because of this advertisement and the fact that all three review leaders were upper-class women, we believe that female students were more likely to participate in this program than males. More than half of the students who attended the weekly reviews also made use of at least one other form of extra help, including one-on-one tutoring through the Chemistry Department, tutoring through the College of Engineering, Chem Central, and/or instructor office hours. We also note that none of the students participating and benefitting from the Connections Chemistry Review decided to switch out of engineering after taking CHEM 1151.

Figure 5 compares the attitudes of males and females who attended the weekly reviews regarding whether chemistry is an important subject to learn to be a successful engineer. This question was posed as a yes or no question on both the pre- and post-surveys given. One hundred percent of females both before and after taking CHEM 1151 felt chemistry is important for being a successful engineer. The percentage of males who felt chemistry was important decreased from 90% before taking CHEM 1151 to 68% after completion of the course.

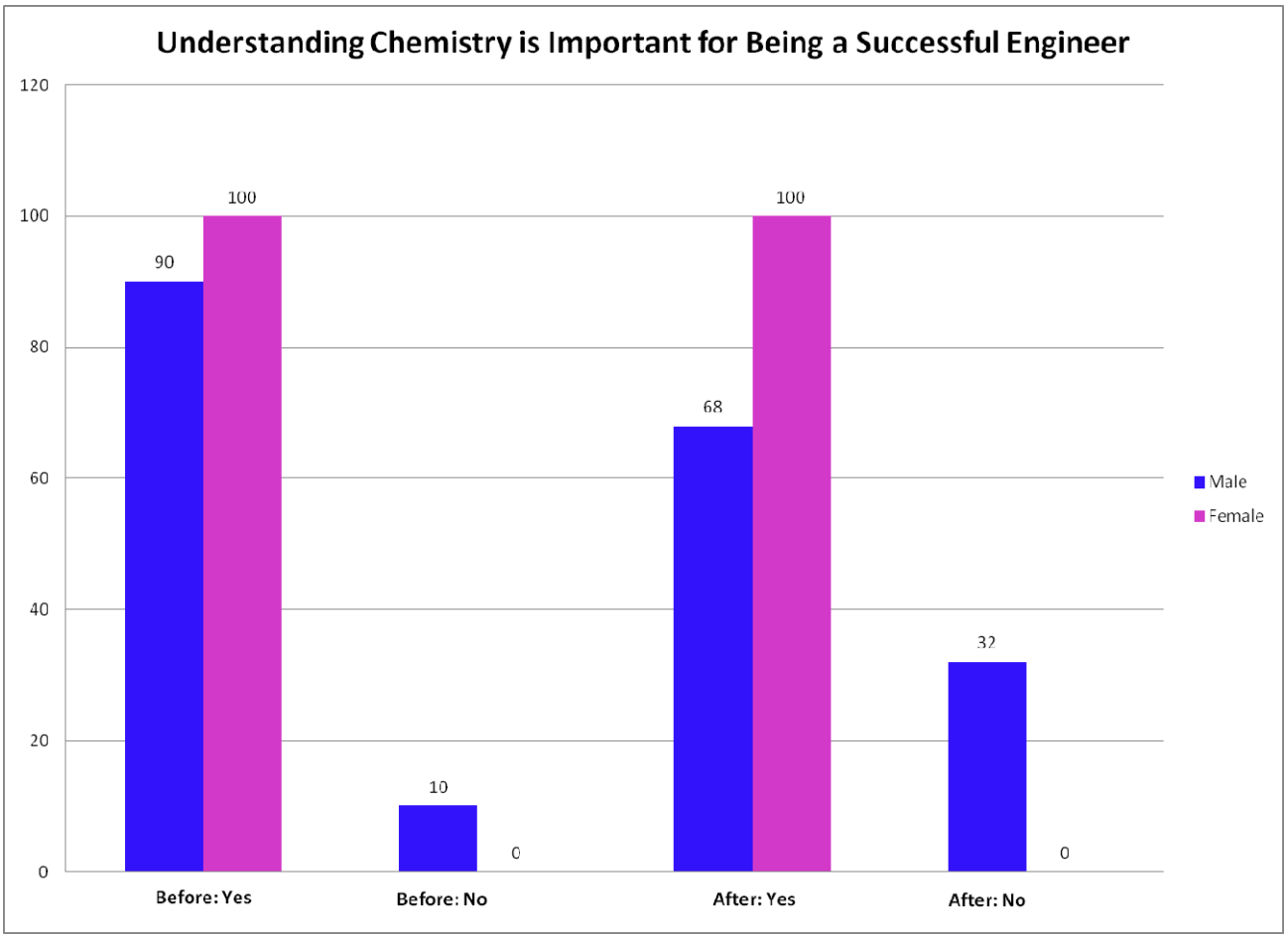

Figure 5

A major underlying goal of the Connection Review Program was to increase the success and retention of women students during their first year of study in engineering. We had hypothesized that female students participating in Connections Chemistry Reviews would be more likely to succeed in CHEM 1151 than their non-participating peers. Figure 6 compares the average grades for midterm exams for male and female students in Groups A, B, and C. For both Groups A and B male students had a statistically higher average than female students, with a confidence level of 95%. However, the averages between males and females for Group C were not statistically significant. From the graph it can also be seen that the midterm averages for Groups A and C were very similar. These data show that students who attended the Connections Chemistry Review sessions benefitted from these sessions and on average were successful in CHEM 1151.

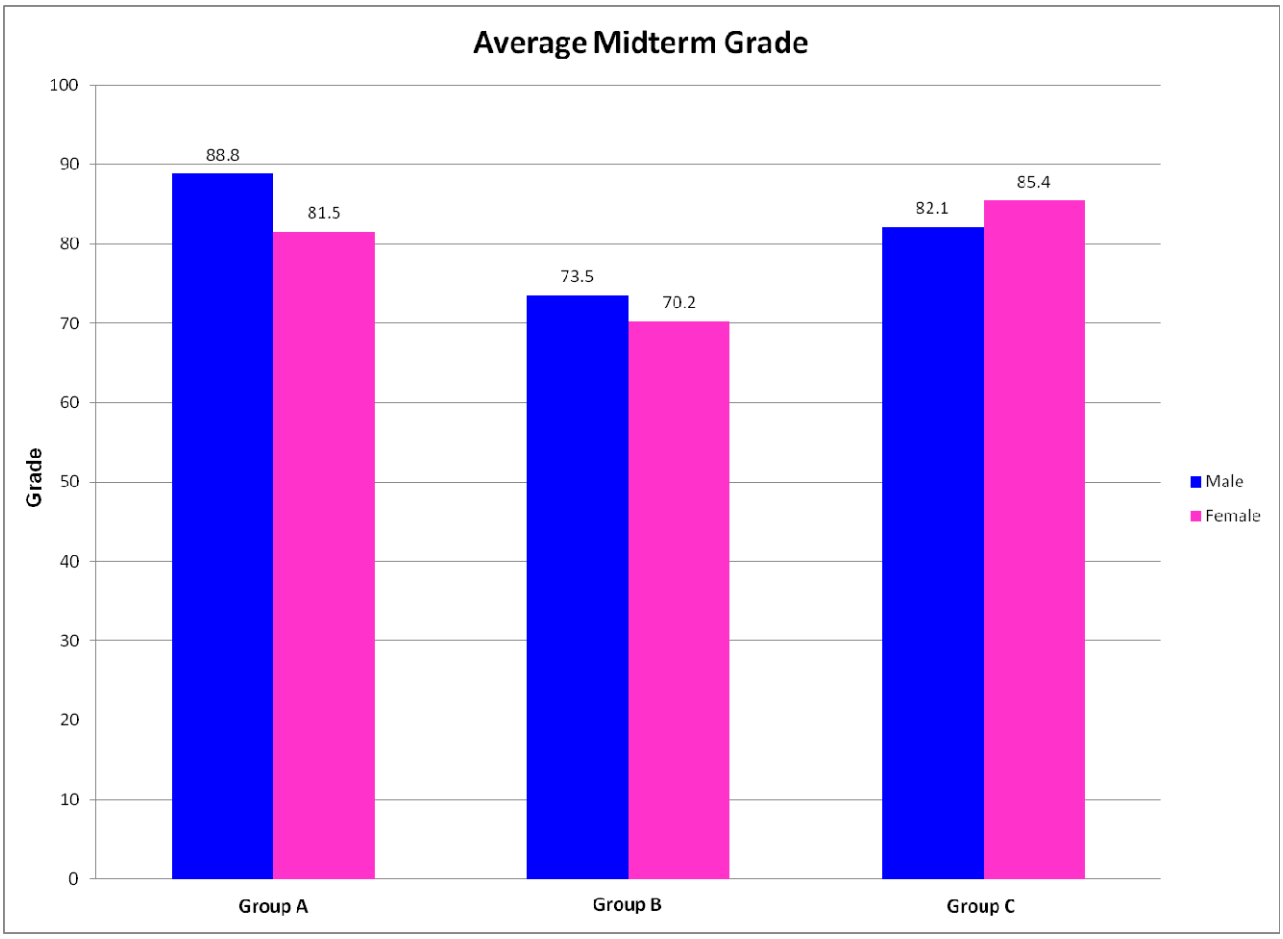

Figure 6

Comments received from students who participated in the weekly review program were insightful:

> *"It was really good to hear the material explained in a different way by people that I could relate to. I felt like the review sessions not only helped me to complete the homework, but also helped me to understand the material in a different way than was taught in a recitation or lecture."*
>
> *"Going over homework was really helpful, especially when those questions were on the quizzes or the midterms. The review sheet was also very helpful."*
>
> *"Tutors were able to explain concepts and answer questions very clearly. Extra tips/tricks/analogies were provided to help students understand chemistry."*
>
> *"<The tutors> explained the material in a 'fun' way."*

"<The tutors> were awesome. I would recommend them as teachers because they know how to explain the materials by breaking them apart."

Conclusions and Recommendations

This paper has presented the survey results from freshmen enrolled in a first-year chemistry course required for students majoring in engineering at Northeastern University. The analysis showed a number of results that were not surprising, such as:

- The less exposure students had to chemistry prior to college, the more likely they were to benefit from extra help resources.
- Freshmen intending to major in Chemical Engineering were well prepared for chemistry and, thus, did well without the supplemental instruction or recognized the need for the review sessions and took advantage of them. Compared to their counterparts in other majors, relatively few both received below average grades and ignored the help.

The analysis also showed:

- The percentage of males who felt chemistry was important for being a successful engineer decreased from 90% before taking CHEM 1151 to 68% after completion of the course while all females indicated it was important both prior to and after completion of the course.

The analysis also indicated areas of improvement:

- Freshmen planning to major in Civil Engineering included a group in most need of help that did not take advantage of the review sessions.
- Students who are freshmen in the College of Engineering but have not yet selected an engineering discipline ("Undecided Engineering") also had lower mid-term grades and could benefit from additional support programs.
- Students who have not yet been formally admitted to the College of Engineering yet but are taking CHEM 1151 as part of a plan to prepare them for possible entry into engineering, had lower mid-term grades and need additional support programs.
- Students may benefit from additional review on the topics covered towards the end of the course.

The feedback received and results from this study will be used by future review leaders, the course coordinator, and instructors to improve subsequent offerings of the program and CHEM 1151. Future plans for this program include implementing strategies to increase participation in this supplemental instruction program and increasing training opportunities for the review leaders.

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