The Influence of Preconceptions, Experience, and Gender on Use of Supplemental Instruction and Academic Success in a Freshman Chemistry Course for Engineers

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Abstract

The purpose of this study was to analyze relationships among students' use of supplemental instruction (SI)—such as tutoring, office hours and group study—in a first-year engineering course, factors that may predispose a student to use such support, and the impact of SI on both grade within the course and GPA after three semesters. Factors considered included a student's self-reported gender, their previous experience with resources for SI, their intended major, and their perception of the importance of the course for their engineering degree. Based on previous demonstration of the association between use of SI in courses taken during a student's first semester in college and long-term academic success, identifying incoming student populations less likely to seek SI resources could be impactful in improving long-term student academic success and retention, particularly of females, in undergraduate engineering programs.

The population considered in this study consisted of students enrolled in the General Chemistry for Engineers course for freshmen during the fall 2016 semester at Northeastern University. Students were surveyed to obtain information on their background and attitudes, to report their experiences with SI prior to entering college, and to evaluate their experiences with SI at the end of the semester. The surveyed population was comprised of 375 students, of which 37% were female. Data for male and female subpopulations were analyzed and compared in order to determine what factors influenced their use of resources for SI during this course and the impact of this use on course grades and GPA after three semesters.

It was found that whether or not a student used SI during their first semester in college had a greater impact on long-term academic success for women than for men, with females who used SI for freshman chemistry tending to have higher GPAs after three semesters than their male counterparts. Prior use of SI in high school was predictive of whether a student used SI during their entering semester. The importance a student placed on freshman chemistry also correlated with the student's use of SI in the course. Students who were undecided in their engineering major upon entering college tended to have higher grades in freshman chemistry and GPAs after three semesters if they perceived chemistry was important for their engineering degree. These findings suggest greater encouragement of the use of SI in gateway science classes by females and students undecided in their engineering major in particular can impact their academic success.

Introduction

Supplemental instruction (SI) has been utilized in academic institutions as a strategy to retain students, particularly females, in their degree programs [1], [2], [3]. To limit attrition in programs such as engineering, universities have provided academic support for first-year students enrolled in the gateway math and science courses that have been historically challenging for students and have prevented or deterred students from progressing to more advanced coursework [4], [5], [6]. With a goal of both limiting attrition and increasing the percentage of female students enrolled in its programs, the College of Engineering at Northeastern University has placed emphasis on identifying factors that predict utilization of SI by freshman engineering students and characterize its impact, with a current focus on the use of SI by freshmen in a required general chemistry course. To learn more about their experiences with SI and academic goals, students enrolled in this gateway science course were surveyed at the start and at the end of the fall 2016 semester. Responses to these surveys then were correlated with recorded student use of resources provided for SI, course grades, and institutional data for GPA and retention in engineering after three semesters to elucidate key factors impacting use of SI and its effects.

This current paper is part of an ongoing study assessing the use and impact of peer tutoring in this required freshman general chemistry course. Data previously reported from this research linked increased course grades for female students with regular attendance of group or one-on-one SI provided by peer tutors [2]. Students who attended SI regularly as freshmen in this course also reported the subject was easier to master than initially anticipated, and students who attended a weekly group review led by upper-level peer tutors had higher GPAs after multiple semesters than those who did not [7]. The ability of peer tutors to explain challenging concepts and problems was identified as a major factor affecting the use of SI [8]. Data from this study also suggested that gender plays a role in how students sought SI. For example, 15% of female students reported gender-based intimidation as a reason to not seek SI [9]. This current paper seeks to build on these previous findings, with a primary focus on analyzing how gender combines with perceptions of a course's importance towards a student's degree program, intended engineering major, and previous high school experiences with SI to affect the use of an array of options for SI as a freshman and subsequent impact beyond the first year.

Use and efficacy of SI by freshman engineering students

Implementation of SI by colleges is grounded in published research indicating its positive impact on grades for freshmen. Fayowski and MacMillan found that students' odds of success in a freshman calculus course were 2.7 times greater with participation in SI [4]. Musah and Ford [10] recently reported a 10% increase in passing grades in introductory chemistry courses for users of SI compared to non-users. Tutoring has been identified as responsible for improving course averages in gateway math, chemistry, and physics courses taken by aspiring bioengineers by more than 18% [11]. Benefits of using SI in such courses have been reported for first-year engineering students regardless of their entering capability [1] and appear to extend to improve a student's grade in all classes, not just the ones directly supported by SI [3]. Other researchers have found improvements in creative thinking skills not often learned in STEM classrooms for students using SI [12]. These improvements appear to require ongoing, consistent participation in SI during the semester, as benefits were seen usually for students who attended multiple sessions

over the course of a semester [13], with structured SI led by an instructor or teaching assistant (TA) providing the most benefits [9].

Previous research also has reported positive effects of using SI as a college freshman that extend beyond this first year. A quantitative study of more than 3900 students reported an 11% increase in graduation rate for students who used SI as a freshman [14]. Other correlations have been found between high GPA at graduation and frequency of usage of SI [7], [13], [15]. Students themselves have linked use of SI with these grade improvements: 38% of the participants in a 2015 study of 500 college students reported a 1.0 grade point or more increase, with 88% crediting SI with their grade improvements to some degree [12]. The proven benefits of SI are particularly important as student retention, especially among under-represented groups such as females in engineering programs, becomes an increasing focus for STEM programs [16].

Gender, preconceptions, and impact of SI

SI, a form of practical help, may be viewed as an example of a developmental relationship supporting the professional growth of aspiring students in engineering programs. The efficacy of developmental relationships for women is a widely-accepted belief among the STEM educational community [17]. For example, Blake-Beard *et al.* [18] found that the provision of practical help can partially neutralize inherent advantages of males who may form the majority of individuals in a class as students and instructors. Outcomes more supportive of women may be made more likely by matching mentor-mentee gender [18], an observation consistent with our previous finding that the gender of an instructor differentially affects a student in gateway chemistry classes in engineering programs depending on the student's gender [7]. Here, it is important to distinguish self-identified gender from gender-associated behaviors, as highlighted in a recent study of more than 750 STEM undergraduates reporting that masculine vs. feminine personality characteristics have distinct effects based on gender [19]. In this present paper, gender specifically refers to a student's self-reported gender and not their biological sex or gendered characteristics.

The current empirical literature examining how SI might differentially benefit female students nevertheless is incomplete. For example, although researchers at the University of North British Columbia [5] found that female students who did not use SI tended to drop out at a considerably higher rate during their freshman year compared to male students who did not use SI, whether there were longer-term differences in GPA and/or retention between genders was not reported. Malm *et al.* [1] concluded that female participation in SI was critical to academic success in challenging first-year coursework for engineers but acknowledged that their single study required further validation with larger populations. Similar issues exist in a recent case study by Neumann *et al.* [20] examining the impact of the continued presence of adverse cultural expectations, such as implicit bias and stereotype threat, on the attitudes and retention of female engineering students.

Whether a freshman's previous experiences with SI in high school have a quantifiable impact on the outcome of subsequent use of SI in college by the student also is unclear. What is by contrast widely understood today is the efficacy of SI for K-12 students within the grade school environment. Frequently the provider for SI at these levels has been an adult (*e.g.*, the class

instructor), but one-on-one peer tutoring is an alternative form that has been shown to benefit recipients [21]. However, although it is expected that both genders benefit from SI with highly-engaged peers, recently it was reported that girls preferentially respond more positively to personal interactions [22]. Further, a recent study of more than 2,900 middle-school students identified that beliefs in competency, mediated by both in-classroom and out-of-the-classroom factors, appear to be a strong component in the subsequent pursuit of STEM studies by females [23]. Given that SI is commonly accepted to strengthen a student's self-efficacy beliefs [24], is it possible that exposure to SI prior to college has a measurable effect during the freshman year of college and beyond? This question brings up an important follow-up: what role does gender have, if any, in these effects?

Study context

To learn more about the impact of prior experience with SI and the effect of perceptions and attitudes towards utilization of SI and course subject, data for students enrolled in a required first-semester general chemistry course for engineering students during the fall 2016 semester at Northeastern University were collected and analyzed. Lecture sections of 70-120 students, meeting three times weekly in 65-minute blocks, were taught by an instructor. These lectures also were divided into recitation sections consisting of approximately 30 students each and led by TAs. These weekly 65-minute recitations reviewed concepts introduced in lectures and provided additional opportunities for question-and-answer. Students' grades in the course were determined by a weighted combination of course participation, homework assignments, weekly quizzes, three midterm exams, and a final exam.

Both group and one-on-one tutoring were provided to students enrolled in this course. Group SI through the "Connections Program" was offered on Monday evenings by upper-class undergraduate tutors, complemented by instructor-led reviews immediately before exams. One-on-one SI was available to students through tutoring by upper-class undergraduates staffing the College of Engineering Tutoring Office, in addition to instructor and TA office hours and a University Peer Tutoring Program. Peer tutors consisted of a mix of men and women. Other forms of SI available for participants in this study included a walk-in help center ("Chem Central"), staffed by faculty and graduate students in the Department of Chemistry and Chemical Biology, and self-organized study groups that students were encourage to join.

Methodology

Data analysis utilized (1) student responses to a pair of surveys, (2) final course averages and recorded attendance at group and one-on-one tutoring, and (3) institutional data for GPA and enrolled academic program after three semesters. IRB-approved surveys were administered in the fall 2016 semester to 375 students enrolled in the course. The population was primarily freshmen registered in the College of Engineering, with a very small number of transfer and other students. A vast majority of students surveyed had taken one or more years of chemistry prior to this course. Surveys were administered electronically using students' electronic devices (or via paper survey upon request) in recitation sections at the beginning ("Pre-surveys") and end ("Post-surveys") of the semester. Only students age 18 and over had the option to take the approximately ten-minute survey, and students could opt out of a survey if they did not want to

participate. Pre- and post-surveys were matched with student grades by asking students to enter their university-assigned student identification number when completing a survey.

To gain an understanding of student-held preconceptions and expectations, survey questions covered student educational backgrounds, attitudes toward the course subject, past use of SI before entering the university, and use of SI during the semester. Results reported in this study were based on student responses to questions posed in the surveys (Table 1).

Table 1: Analyzed Survey Questions, Response Options, and Survey Administration Period

Survey	Question	Response Options
Pre	What is your gender?	• Male • Female
Pre	Which one of the following is your (intended) major?	• BioEngineering • Chemical Engineering • Civil and Environmental Engineering • Computer Engineering • Electrical Engineering • Industrial Engineering • Mechanical Engineering • Undecided Engineering • Other
Pre	Did you use 1-on-1 tutoring, instructor's office hours, and/or study groups in high school?	• Yes • No
Pre & Post	Is understanding chemistry important to being a successful engineer?	
Post	Rate the usefulness of Monday night Connections Reviews.	A Likert rating scale from 1-5, where 1 represents low usefulness and 5 represents high usefulness.
Post	Rate the usefulness of the COE Tutoring Center.	
Post	Rate the usefulness of Chem Central.	
Post	Rate the usefulness of the University Peer Tutoring Program.	
Post	Rate the usefulness of instructor/TA office hours.	
Post	Rate the usefulness of instructor-led reviews.	
Post	Rate the usefulness of studying in groups.	

Survey data from the fall 2016 semester were collected and analyzed to find similarities, differences, and trends. The population considered for this analysis included students receiving a letter grade in the course who participated in both the pre- and post-surveys. This consisted of 375 students, with 237 (63%) males and 138 (37%) females, and represented 65% of the total population of students enrolled in the course during this semester. The enrollment in the course was 66% male and 34% female. Surveys were validated based on a sequence of establishing face validity by review of question topics and phrasing, conducting checks of internal self-consistency involving comparisons among survey questions and data provided by instructors, building on analogous "pilot" surveys administered in previous years, and cleaning and coding

collected data for organization. For analysis on populations larger than 30, a *z*-test was used; if populations were less than 30, a *t*-test was used. One-tailed *z*- and *t*-tests were used to determine if one population value was statistically significantly higher than another. These tests determined statistical significance by comparing population size, mean, and standard deviation. For the proportion *z*-tests and regular *z*- and *t*-tests used, calculated *p* values were compared to the 0.10 threshold value for statistical significance, indicating a 90% confidence level. A *p* value that was less than the threshold indicated statistical significance.

Results and discussion

Academic success and use of SI for female students

In order to understand how gender affects the use and impact of SI, the relationship between use of SI and a student's academic success was explored, as summarized in Table 2. For this study, SI included both group and one-on-one peer tutoring, instructor/TA office hours and reviews before exams, department and university help centers, and study groups self-organized by students. No statistically significant difference in course average was found between students who did *vs.* did not use SI during the semester.

Statistically-significant differences based on one-tailed *t*-tests, however, were observed for the relationship between a student's use of SI and their GPA after three semesters. Females who used some form of SI in the freshman chemistry course tended to have a higher third-semester GPA than their male counterparts. In contrast, females who did not use some form of SI in this course tended to have a lower third-semester GPA than their male peers.

These findings together suggest that using SI as a freshman offers women more benefits towards their long-term success in their engineering studies than men. Although the benefit of SI for females may not be manifested in course grade during a given term in which SI is used, the longer-term association of use of SI with higher GPA suggests an additional rationale to motivate supporting use of SI among female students.

Table 2: Effect of Gender and Use of SI on Course Average in Freshman Chemistry and GPA after Three Semesters

	Used SI for Freshman Chemistry			Did not Use SI for Freshman Chemistry		
	Females	Males	*p* value	Females	Males	*p* value
Course Average	89.5±8.6	89.6±8.2	0.457	92.0±8.9	95.1±6.5	0.188
GPA After Three Semesters	3.52±0.36	3.44±0.45	0.021	3.33±0.43	3.58±0.28	0.068

Use of SI, intended major and student perception of subject importance

In order to understand further what may cause a difference in academic performance between genders, the relationship between the importance a student placed on a course and their use of SI in this course was explored. Students were asked in both pre-surveys at the start of the semester

and post-surveys at the end of the semester to rate how important they felt the required chemistry course was to their overall engineering studies. As shown in Table 3, a statistically significantly higher proportion (based on a one-tailed *z*-test with a *p* value of 0.025) of students who felt chemistry to be important at the start of the semester used SI during the semester than students who did not feel chemistry to be important. Furthermore, as shown in Table 3, among those who reported chemistry as important at the beginning of the semester, a larger proportion of those who used SI reported chemistry remained important at the end of the semester than those who did not use SI (*i.e.*, students who used SI were less likely to change their minds about the course's importance than those who did not use SI). Together, these findings suggest that the perceived importance of learning a gateway science subject by an engineering student may be associated with the use of SI for the course.

Table 3: Relationship Between Perceived Importance of Course and Use of SI in Course

Percentage	Perceived Importance of Chemistry			
	Important at Both Start and End of Semester	Not Important at Start But Important at End of Semester	Important at Start But Not Important at End of Semester	Not Important at Both Start and End of Semester
Students Using SI This Semester	81.4%	1.1%	13.8%	3.7%
Students Not Using SI This Semester	66.7%	0.0%	25.0%	8.3%

Subgroups of each gender based on major then were explored in order to understand how perceived importance of a required subject, gender, and long-term success are related. Students who had not declared their engineering major upon enrolling in the course were considered to be undeclared engineering majors. Note that students at Northeastern University do not need to declare their major until the end of their freshman year. Table 4 shows that females undecided in the specific discipline for their engineering major had a statistically significantly lower course average (based on a one-tailed *z*-test) than their male counterparts.

Although this difference was small, the statistical significance in the difference infers that gender does have a relationship with success for undecided engineers, and motivates analysis of strategies to better support female students. Furthermore, even a difference of 2.5 points in a course grade can be important to engineering educators and administrators. No such difference was found between genders for students intending to major in the chemistry-related engineering disciplines of chemical engineering and bioengineering. Together, these findings may enable the development of further SI interventions targeting females who are undecided engineering majors.

Table 4: Effect of Gender and Intended Major on Course Average

Intended Major	Course Average		
	Females	Males	*p* value
Chemistry-Related	89.6±8.4	90.7±8.3	0.263
Undecided	87.9±9.5	90.3±8.1	0.054

Table 5 shows how perceived importance of chemistry by females in pursuit of their engineering degree correlated with intended major. It was found using a one-tailed *z*-test that females who were undecided in their engineering major tended to rate chemistry as less important than those intending to major in a chemistry-related engineering discipline. This finding suggests that, because females in undecided engineering majors place reduced importance on the course, they achieve lower grades in the course compared to their male counterparts. This outcome also provides further evidence that the importance an engineering student places on a required freshman gateway science course may be a predictor of their grade in the course.

Table 5: Effect of Intended Major on Perceived Importance of Course Subject for Females			
	Intended Major		
	Chemistry-Related	Undecided	*p* value
Proportion of Females Rating Chemistry as Important	1.000 (53/53)	0.904 (47/52)	0.010

To understand the longitudinal impact that perception of importance may have on females undecided in the discipline for their engineering major, the direct relationship between a student's perception of chemistry's importance and continued success in their pursuit of an engineering degree beyond the course was analyzed. Table 6 shows that students undecided in discipline for their engineering major who felt chemistry to be important to their degree had a statistically significantly higher course average, using a one-tailed *z*-test, than those who did not.

In a longitudinal extension of this finding, a one-tailed *z*-test also identified that students undecided in choice of engineering discipline for their major had higher third-semester GPAs if they had rated (as an entering freshman) chemistry as important to their degree. This result, in consideration with previously discussed findings, offers a strong argument for encouraging female students to use SI. The association of SI with course importance, and therefore long-term success, suggests that females in engineering could see higher achievement with increased use and access to resources for SI.

Table 6: Effect of Perceived Importance of Course Subject for Students Undecided in Major Upon Entering College on Course Average and GPA After Three Semesters			
Academic Outcome	Perceived Importance of Chemistry		
	Important	Not Important	*p* value
Course Average	90.4±8.6	87.5±8.1	0.005
GPA After Three Semesters	3.48±0.42	3.40±0.39	0.100

Use of SI in past and present, perceived subject importance, and student academic success

With a better understanding of the relationship between a student's perception of a course's importance, use of SI, and their academic success, analysis of a student's past SI use was conducted. By investigating a student's perception of chemistry's importance and their prior use of SI, it was found using a one-tailed *t*-test that a higher proportion of students who felt chemistry to be important used SI in the past than those who did not, as depicted in Table 7.

Table 7: Effect of Perceived Importance of Course Subject on Proportions of Students Seeking SI in High School			
	Perceived Importance of Chemistry		
	Important	Not Important	*p* value
Proportion of Students Seeking SI in High School	0.854 (302/354)	0.579 (11/19)	0.001

This finding suggests that prior exposure to SI may be correlated with the perceived importance of learning a gateway science subject, something that has been demonstrated above to impact future success. Furthermore, as shown in Table 8, a one-tailed *z*-test demonstrated that a higher proportion of previous users of SI again used SI during their fall semester in chemistry than those who did not use SI in the past. This correlation implies that prior experience with SI in high school may motivate a student to be more inclined to pursue SI as a college freshman. Together, these findings strengthen the potential linkage between use of SI, both in high school and college, and the importance a student places on learning in a course.

Table 8: Correlations Between SI Use in High School and College			
	Students Who Used SI in High School	Students Who Did Not Use SI in High School	*p* value
Proportion of Students Using SI During First Semester in College	0.961 (298/310)	0.800 (48/60)	0.001

In order to understand whether past use of SI leads to different outcomes for different genders, relationships between self-reported gender and reported use of SI in high school were examined. Table 9 shows that, using a one-tailed *z*-test, while male students who had not used SI in the past had a higher course average than males who did partake in the past, the same was not found for female students.

One possible interpretation is that prior use of SI in high school by females is sufficient to enable an equivalent level of success in a more advanced college course, but that the use of SI in high school by males to overcome academic challenges may be insufficient to boost these students to the same level of subsequent performance in the subject as their more capable male peers who did not need the extra help. It should be noted that, although the difference in course averages between subsets of males was less than 3 points, it carries statistical significance and, as previously discussed, even small differences in grades are important to students, as well as engineering colleges who hope to see all of their students succeed.

Table 9: Effect of Gender and Use of SI in High School on Course Average			
Gender	Course Average		
	Used SI in High School	Did Not Use SI in High School	*p* value
Female	89.7±8.6	89.3±6.3	0.434
Male	89.6±8.5	92.3±8.5	0.010

Although prior use of SI by females in high school did not result in an increase in grade in the gateway chemistry class in college, it did impact these students in their overall academic performance into the sophomore year. Table 10 shows that among those students who did use SI in high school, females tended to have a higher third-semester GPA than male students based on a one-tailed *z*-test.

Table 10: Effect of Gender on GPA after Three Semesters for Students Who Used SI in High School			
	Gender		
	Females	Males	*p* value
GPA After Three Semesters	3.51±0.36	3.44±0.45	0.074

However, among those students who did not use some form of SI in high school, males had a statistically significant (based on a one-tailed *t*-test) higher third-semester retention in engineering than their female counterparts (Figure 1). This pair of findings points to potential longer-term benefits females in collegiate engineering programs see with experience using SI in high school compared to their male counterparts, whose SI experience appears to have no statistically significant impact on their post-secondary academic behaviors. This outcome strengthens the case for promoting early involvement in SI for female engineering students.

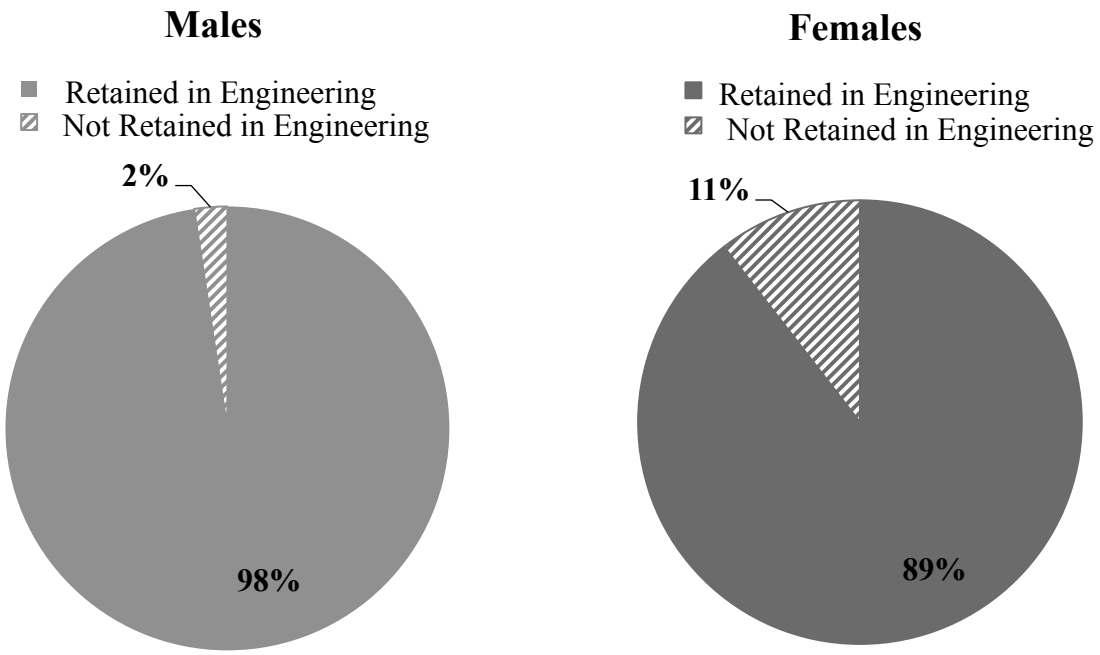

Figure 1: Retention in engineering disciplines after 3 semesters for students who did not use SI in high school

Conclusions

Analysis of student-reported gender, use of SI, intended engineering discipline for major, and perception of the importance of a gateway science course suggests that encouraging increased involvement in SI among female engineering students can impact their academic success. As the retention of female students in engineering disciplines is an important goal for many institutions, the findings presented here may provide important guidance to enable schools to better support their female undergraduates.

When considering the impact of using SI during the fall semester of their freshman year, it was found that:

- Females may benefit more than their male counterparts from using SI in the long term, as women show improved performance with SI use, and diminished success with a lack of use, in comparison to men.
- The importance that a student places on a gateway science course as relevant to their engineering degree and their likelihood of maintaining that attitude are directly correlated with SI usage.
- Among students undecided in their engineering major, a group where females tend to perform worse in comparison to their male counterparts, the importance a student places on the course is associated with long-term success.

In conjunction, when prior use of SI in a student's high school is considered, it was found that:

- The importance towards their engineering degree a student places on a gateway science course and their prior use of SI in high school are both associated with continued use of SI in college.
- Prior use of SI in high school is associated with improved GPA in the sophomore year for female students compared to their male counterparts; not using SI in high school is associated with lower retention in engineering by the sophomore year for women compared to men.

These findings motivate further clarification of predictors based on a student's background and experiences for whether a given student uses SI and the efficacy of this SI on their grades within gateway science courses, and their longer-term academic success and retention in engineering programs. Considering these effects, including graduation rates and GPA at graduation, warrants collecting further data for the surveyed population for a period extending additional years beyond their entrance to college in 2016. Other important questions to consider in the future include: how does the use of SI within a freshman science class help develop strategies that an engineering student can apply to increase their subsequent academic success? What specific factors at Northeastern University promote the beneficial impact of SI on female students?

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