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Measuring the Impact of an Enrichment Program for First-Term Undergraduate Engineering Students in Mathematics and Engineering Curricula

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Abstract

First-year students frequently struggle with the transition from high school to college as they juggle academic requirements, new living accommodations, and social expectations. Transitional struggles can be amplified for engineering students due to the challenging mathematics, engineering, and science courses taking during their first term. First-year students are commonly ill-equipped to manage their time wisely and study properly. Structure and guidance can assist in fostering skills and behaviors that are vital for success.

The SUCCESS Scholars (SS) Program was developed to provide foundational support for 24 low-income first-year engineering students. The program was designed to provide academic support in the form of extra Fridays sessions for engineering and peer mentorship led supplemental instruction (SI). The 24 students were grouped into exclusive sections of a precalculus course and an engineering course. Two upper-level students were selected to lead the SI sessions while providing peer mentorship and community engagement for the first-year students. The faculty teaching both courses worked together with the peer mentors to develop a plan for the SI sessions.

This paper will detail the SS Program and analyze the performance of the students in their first quarter at the university. Data from common exams given in their precalculus and engineering courses will be used to examine the effectiveness of the program.

Motivation

First-year engineering students are at-risk for high attrition rates [1], [2]. Social issues, independence, adapting to a new environment, foundational knowledge, and other factors have been determined as possible challenges faced by students entering college [3]. The prerequisite skills required in an engineering program leave students more likely to experience these challenges [2], [4]. First-year engineering students are often simultaneously enrolled in core math, engineering, and science courses which require strong fundamentals and involve computationally intensive content [2], [5].

Efforts have been made to better understand these transitional challenges for first-year engineering students [6]. Tinto's Model of Integration emphasizes the importance of academic and social integration for first-year student success [7], which has been used as the foundation for models related to engineering retention in engineering education [2], [8]. University of Michigan faculty applied a modified version of Tinto's model to study the role of college knowledge and proactive behavior in co-curricular activities of first-year students. The study emphasized the need for efforts to provide first-year students with positive framing mindsets through experiences that focus on productive habits. "Participation in these kinds of activities, in turn, are likely to have beneficial effects on a variety of outcomes including social capital, engineering identity, and professional aspirations [8]." A model at University of Michigan [2] was developed for first-year engineering student retention that placed heavier emphasis on academic integration over social integration due to the academic rigor faced by first-year engineering students and evidence indicating engineering students who are not successful in their first term are at high risk for attrition. Success markers like first-year GPA are credited as significant influences on decisions to persist in engineering [2]. Building confidence and competency while fostering good habits that students can carry into subsequent courses by providing quality academic support may improve retention.

Supplemental instruction (SI) is a widely accepted method of academic support [9]-[20]. SI may provide students with benefits such as problem-solving skills which can persist beyond the current course [9] and social support network [10]. SI is defined as "a program designed to proactively address student performance in high risk courses [11]." SI "consists mainly of optional supplemental instruction sessions" with the following characteristics: (1) proactive, not remedial, (2) not traditional review sessions, (3) attendees are active participants, (4) leaders explicitly model study and test-taking strategies within the context of the course's content, and (5) SI leaders mirror the content of the course rather than teach new content [11].

A vital component of establishing an SI program is the choice of session leaders. Using upper-level students in this role can "create a lower-risk atmosphere for the students, and frees them to ask questions and to work through problems themselves with less worry about professors seeing their mistakes [12]." These leaders serve as subject matter experts during SI sessions. This can help to establish a peer-to-peer connection that may evolve into a resource students utilize for general academic and social development [12]-[15]. This relationship can be a mutually beneficial experience for the peer mentors [13], [14]. Leading SI sessions and taking on the role of peer mentor can foster communication, teamwork, and leadership skills along with increased self-confidence [13].

UT Austin has a history of implementing SI programs for engineering courses which have shown beneficial impacts and noted measurably improved course grades of students who attend [9], [15]-[18]. Penn State University incorporated SI into two mechanical engineering courses. After which they cited an intent to expand the SI program to additional engineering courses and departments based on the positive results experienced with students who participated in their SI program [11]. SI programs have also positively impacted students in mathematics courses [12], [19]. A study published by faculty at California State University demonstrated an improvement in student performance in calculus from participation in their SI program [12]. The Citadel also successfully implemented an SI program in their precalculus and calculus courses to increase student retention [20].

SI programs have been predominantly designed to supplement one specific course [9]-[20]. First-year engineering students who face challenges in both engineering and mathematics may benefit from an integrated supplemental instruction program created through a collaboration across departments that provides support for *both* courses. This paper provides an account of the SUCCESS Scholars (SS) Program at Louisiana Tech University, which implemented SI sessions as part of an enrichment program to provide academic support for *both* the engineering and precalculus courses required by first-quarter engineering students. The performance of 24 students in this program during the Fall quarter of the 2022-23 school year is evaluated to answer the following questions.

1. How did the SS program impact student performance on their precalculus midterm?
2. How did the SS program impact student performance on their precalculus final?
3. How did the SS program impact student performance on their engineering midterm?
4. How did the SS program impact student performance on their engineering final?

Background for First-Year Engineering Program

Louisiana Tech University operates on a quarter calendar but awards semester credit hours (SCH). The accelerated course delivery of the quarter system exacerbates the challenges in the first term mentioned in the literature. Classes are scheduled to meet for longer periods of time than classes at a typical semester school. For example, a 3 SCH course meets for 225 minutes each week of an 11-week quarter. A student is considered a full-time student when enrolled in a minimum of 8 SCH and a maximum of 12 SCH.

All first-year engineering students at Louisiana Tech University, regardless of engineering discipline, participate in the Living with the Lab Engineering Curriculum (LWTL). In the first quarter, all students in a particular engineering section are also enrolled in a common math section. This is referred to as a "block" schedule where the students in both sections move together as a cohort for that quarter. Table 1 outlines a typical schedule for first-year engineering students with the math and engineering block highlighted in gray.

Table 1. Block schedules taken by first-year engineering students.

Fall Quarter	Winter Quarter	Spring Quarter
ENGR 120 (2 SCH) Problem solving, circuits, CAD, fabrication, programming	**ENGR 121 (2 SCH)** Conservation of energy, heat transfer, forces, control systems	**ENGR 122 (2 SCH)** Statics, engineering economics, design project
Math 240 (3 SCH) Pre-calculus algebra & trigonometry, logic, matrices	**Math 241 (3 SCH)** Single variable differential calculus	**Math 242 (3 SCH)** Integral calculus, introduction to statistics

CHEM 100 (2 SCH) General chemistry	**CHEM 101 (2 SCH)** General chemistry	**PHYS 201 (3 SCH)** Mechanics
FYE 100 (1 SCH) First Year seminar	**CHEM 103 (1 SCH)** General chemistry lab	

The block schedules are strategically designed to provide multiple benefits to the students including but not limited to community building and engagement. The block schedules give the students the opportunity to make connections with their peers in their math and engineering classes which consist of the same students. This structure helps them to form study groups as well as feel a sense of community with their peers and the college. Additionally, by having the classes blocked together, the math and engineering courses can draw from each other to make connections and further drive the importance of the concepts in both classes.

Traditionally, there are two versions of the first-year engineering course sequence: HNRS and ENGR. All students taking ENGR/HNRS 120 in their first quarter must have an ACT MATH score of 26 or have received a college equivalent credit for College Algebra. Students who have a 28 or higher are offered the ability to enroll in an HNRS section until capacity is reached. In the Fall 2022-2023 quarter, nine sections were ENGR and seven were HNRS. ENGR and HNRS cover the same material. HNRS have a lower enrollment limit. The max size for an HNRS section is 24, and the max size for the ENGR section is 40. Both versions are given the same common exam. Both meet twice a week on Monday and Wednesday or Tuesday and Thursday. While there are sections of MATH 240 reserved for honors student enrollment, unlike in engineering they are identical in all aspects including enrollment limits. The MATH 240 classes meet three days a week.

Description of the SUCCESS Scholars (SS) Program

The SS Program was advertised during the 2022 summer orientation sessions. Interested students were asked to complete an application that was reviewed by a team of faculty and staff. The grant funding the program required the students satisfy the following conditions for eligibility:

1. Be citizens of the United States
2. Be enrolled at least half-time
3. Classify as low-income status
4. Demonstrate unmet financial need
5. Demonstrate academic ability, talent, or potential

Of the sixty applicants, twenty four were chosen to participate in the SS Program. The majors of the selected students included mechanical, electrical, biomedical, civil, cyber, and chemical engineering. At the end of the Fall quarter two students withdrew from the SS program to pursue non-engineering disciplines.

The program included financial and academic support as well as professional and career development. The SS students were enrolled together in an ENGR 120/MATH 240 block. The support provided by the SS Program will evolve to the changing needs of the students as they progress academically. The primary components of academic support during their first quarter were an extra engineering class session each Friday and SI sessions that supplemented both ENGR 120 and MATH 240 content.

Components of SS Enrichment

The SS students met for nine additional Friday ENGR 120 sessions as an additional form of enrichment during the quarter. These meetings provided increased contact hours with their instructor and access to the laboratory space. Goals for these sessions included community building, working practice problems with feedback from their instructor, open-ended project work, and reviewing course concepts.

Due to the inclusion of the Friday sessions for ENGR 120, the SI sessions had a bias towards math. Out of the 30 total SI Sessions, 13 were exclusively MATH 240, 6 were exclusively ENGR 120, and 11 were hybrid.

There were thirty-one SI sessions available over the course of the ten-week quarter. A typical week consisted of four sessions. These were offered Tuesday/Thursday from 10AM-12PM and Monday/Wednesday from 3:30PM to 5:30PM. These times were strategically chosen outside the scheduled class restraints of the SS students. The average attendance of each SI session was 58%.

Figure 1. SS students attending and SI session.

Two peer mentors in their second year were selected to lead the SS students through the SI sessions. The peer-mentors were chosen from a group of students who completed a pilot version of the SS Program the previous year. Weekly meetings between the peer mentors and the instructors of the math and engineering courses were used to plan the following week’s SI sessions according to need. Common session types included:

- HW - Informal open-ended sessions where students met on one floor at the University Library designed for study groups. Peer mentors were in the room to answer questions and guide the SS students when needed, but did not actively lead content sessions.
- SLAMS - Extra practice problems that are similar to in-class examples and homework problems
- Test Prep - mock exams and timed challenge problems
- Concept Enrichment - Deeper dive into concepts from class

Demographic of the Study

Conditions setforth in the grant required the SS students be selected through an application process, precluding a random sample. Although selection bias cannot be ruled out completely, comparisons between the populations of the SS group and the other students in the study to check for any obvious differences. Table 2 compares the demographics of the SS students with other students in ENGR 120 and Math 240. The data gathered for this study was limited to students enrolled in their first quarter at the college. A pilot version of the Math 240 course was being tested in the same quarter. The SS students were not part of this pilot so all data from the pilot is excluded. An effort was made to keep the makeup of the SS group as similar to the overall incoming population as possible.

Table 2. Demographics of the SS students with other students in ENGR 120 and Math 240.

	N	% Male	% Female	% HNRS	Average Overall ACT	Average Math ACT
SUCCESS Scholars	24	70.83	29.17	20.83	27.04	26.92
ENGR/HNRS 120	346	78.90	21.10	31.79	27.79	27.57
MATH 240	208	76.44	23.56	38.76	28.39	27.87

Analysis

Quantitative data was gathered in the form of common exam scores and final grades for math and engineering. Qualitative data gathered included survey questions and letter grades for math and engineering courses. As the most direct form of comparison between the SS students and others, this analysis focuses on the common exam scores.

In ENGR 120, two common exams were given in the form of a midterm and a comprehensive final. The midterm focused on electricity fundamentals, circuit analysis, Arduino programming, Excel, and SolidWorks. The final exam covered pre-midterm content along with pump efficiency, linear regression, and analog to digital. The exams were administered from 7 to 9 PM for all students enrolled in ENGR/HNRS 120. The problems were multiple choice with no partial credit. Both the midterm and final had a maximum score of 105 points.

In MATH 240, two common exams were given in the form of a midterm and final. The final exam in math is not comprehensive. The midterm covered algebra, logic, and linear algebra while the final exam focused on trigonometry. The exams were administered from 7 to 9 PM for all students enrolled in MATH 240. Questions were free response and graded for partial credit. To ensure grading was uniform across all sections, each instructor in the course was assigned a set of questions to grade across all exams. The midterm had a maximum score of 150 points, while the final exam had a maximum score of 100 points. One SS student withdrew from MATH 240 before the Midterm. Three more withdrew before the final.

An analysis was conducted comparing the performance of the SS group on each common exam to other students in their first quarter at the college. Since the exam scores were not normally distributed and the sample size of the SS group was small, a one-tailed Wilcoxon Rank Sum test was used. A 5% significance level was determined in advance. The results of the tests show a significant positive shift in scores for each common exam for the SS students. Tables 3, 4, 5, and 6 summarize the analysis for the engineering midterm, engineering final, math midterm, and math final, respectively.

Table 3. Analysis of student performance on engineering midterm.

Engineering Midterm	N	Average	Median	Standard Deviation
Non SS group	336	79.35	83	17.34
SS group	24	87.54	93	16.29
			p-value = 0.004267	

Table 4. Analysis of student performance on engineering final.

Engineering Final	N	Average	Median	Standard Deviation
Non SS group	321	77.88	82	17.60
SS group	24	86.54	90	15.33
			p-value = 0.00497	

Table 5. Analysis of student performance on math midterm.

Math Midterm	N	Average	Median	Standard Deviation
Non SS group	202	110.81	114	24.98
SS group	23	122.30	124	18.25
			p-value = 0.01773	

Table 6. Analysis of student performance on math final.

Math Final	N	Average	Median	Standard Deviation
Non SS group	172	77.75	79.75	14.26
SS group	20	87.45	90	8.28
			p-value = 0.0002741	

Discussion

The differences in standard deviations is a concern, especially for the math exams where the difference is more pronounced. Heterogeneity of variance is assumed in the Wilcoxon Rank Sum test and violating this can increase the probability of a type-I error [21]. This can be partially mitigated in the future by expanding the study to more equal sample sizes.

The nature of SI may lead to smaller variance, which could be a desirable outcome. High performing students who would have scored well without the SI sessions may receive less benefit than borderline students. A smaller variance could be indicative of the SI sessions being more beneficial to those who would have struggled more in their absence.

Following the Fall 2022 quarter, a survey was given to the SS students to provide feedback on their perception of the SI sessions. Nineteen of the twenty-four responded. While a more in depth look at the survey is planned for the future, an initial review of the feedback indicates all respondents viewed the SI sessions as beneficial to their overall course grades in math and engineering. They also had unanimous positive reflections on the community building aspects of the SI sessions. Some sample responses to the prompt “Do you think the community building aspect of the SUCCESS Scholars Program helped your performance in the math and engineering classes? Explain” are:

> *“I do because it helps me make friends with my classmates and we do a lot of homework and studying together. It also helped because we help each other with concepts that someone in the group is struggling with.”*
>
> *“I think it did. The community building aspect made me feel more comfortable asking questions to my fellow classmates and to our peer mentors. Without this community that we have, I may not have felt as comfortable asking questions about topics I needed help with, therefore lowering my understanding of the topics we learn in our engineering and math classes.”*
>
> *“Yes, I think the community building aspect allowed all of us students to connect and really get comfortable enough to ask questions that we might have been embarrassed to before or even have fun with our class and professor. I’ve made some really good friends that I can depend on when I need them and have grown very comfortable with all of my professors.”*

As indicated in the literature [12]-[15], the SI sessions can be beneficial to peer mentors. When asked to reflect on how the experience of SI leadership affected their personal development, the two peer mentors provided the following narrative:

Peer Mentor A - “*Being an SI lead has presented me with more ways to grow than I had ever expected. My primary intention of pursuing the peer mentorship lead was to further improve and develop my interpersonal skills. While I did achieve my goals, more experiences and skills that I had never expected to be able to get from the program arose. I feel confident that my time working alongside the students has taught me effective communication and instruction skills. Now, when the students reach out to me to ask for aid, I find that I am able to better oblige than I would have previously.”*

Peer Mentor B - “*Being an SI leader has taught me more about myself than I ever thought it would. Going through junior high and high school, I realized that I did not have to study much or study at all to make the grades I wanted. This all changed when I started my freshman year in engineering. Everything started off great with classes, but I found that my biggest struggle was time management. There would be weeks that I would have three big tests in a week along with keeping up with ongoing assignments. At the start of this year, I finally felt that I knew how to manage my time and study properly. After becoming a peer mentor for this group, I feel that teaching the students how I manage my time has made me more accountable and wanting to set the best example possible*.”

Conclusions

While measuring the exact effects of the SS Program can be challenging due to sample size, all indications show the program provided significant benefit to the SS students in their first quarter. While this paper focused on the first quarter experience of the SS students, the students will continue to be supported both academically and financially as they make academic progress. Enrichment opportunities will evolve based on the changing academic needs of the students with increasing focus on career development in later years. Future studies to understand the full impact of the SS Program over the course of their academic tenure are expected.

Given the measured success of the SS students in their first quarter, the expansion of an integrated math and engineering peer mentor led SI program could be worthwhile. Bringing the support this program provides to a broader range of incoming students in the first-year engineering curricula may have an impact beyond this small subset of students leading to a positive effect on grades and retention rates on a larger scale.

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