Skillset Shifts in First-year, First-semester Chemical Engineering Students

Kyle F Trenshaw
STEM Specialist at the Center for Excellence in Teaching and Learning
University of Rochester

Emily A Weber
Adjunct Lecturer in Biology
Nazareth College and St. John Fisher College

Rachel Monfredo
Lecturer and Senior Technical Associate in Chemical Engineering
University of Rochester

Students' self-assessment of the academic success skills often suffers from a disconnect from the reality of their situation. At the beginning of their first year, students may consider themselves to be excellent at studying based on their success in high school, or they may expect to be behind because of a perceived deficit in their preparation compared to others. However, by the end of that first semester on campus, students usually have a better sense of where they stand in terms of their study habits, time management skills, and general help-seeking behaviors. To better understand how this process of self-discovery occurs for students entering the University of Rochester with an interest in chemical engineering, we administered the Academic Success Skills Survey [1] to four cohorts (F2016, F2017, F2018, and F2019) of first-year, first-semester students in an introductory chemical engineering course called "Sustainable Energy" (CHE 150). In the survey, we asked students for a self-assessment of their academic success skills at both the beginning and end of the semester. We also asked how much of their shift in skillset during the semester students attributed to the CHE 150 weekly workshops and assignments. In this manuscript, we share our results in the form of students' normalized gains in academic success skills as well as a narrative analysis of shifts in their skillsets as a function of both their evolving understanding of college life and the experiences and assignments they interacted with during the semester in CHE 150. Overall, our results suggest that the first semester is a crucial time to cultivate not only skills students will need to succeed as they progress through the chemical engineering curriculum, but also their locus of control around their own studying and success.

Background and Motivation

In 2005, representatives from the National Academies of Science, Engineering, and Medicine gathered at a symposium to discuss the economic, political, social and societal impact of growing global competition for producing the best skilled workforce in the science, technology, engineering, and mathematics (STEM) fields [2]. The goal was to identify and make recommendations for how the US could maintain its perceived lead in technological innovations. Despite the importance of increasing capable STEM graduates, results from the Trends in International Mathematics and Science Study (TIMSS) conducted every 4 years since 1995 show in 2015, the last year of available data, that the US has been measurably behind other countries in assessed skills in science and mathematics at the 4^{th} and 8^{th} grade levels for the last 20 years

[3]. The top performers include Singapore, Korea, Hong Kong SAR, Chinese Taipei, and Japan for mathematics, and the Russian Federation, Singapore, Korea, and Japan for science at the 4th grade; Singapore, Japan, Chinese Taipei, Korea, and Slovenia at the 8th grade. The TIMSS does show a decrease in the gender gap between boys and girls in the United States between 1995 and 2015, and a growing number of countries worldwide show higher achievement among girls than boys, especially in science by 2015 [3]. The concerns of the representatives of the National Academies in 2005 sparked initiatives to encourage more interest in STEM. Efforts initiated at the state level to increase the numbers of students pursuing higher education in the STEM fields have improved interest in STEM majors in college. Support for activities such as the Lego Mindstorm robotics competitions, first launched back in 1998, spurred increased interest in programming with interactive sensors, motors, and features that would allow a properly programmed robot at act autonomously [4], and this is only one of the many STEM-supportive programs that have been developed since the late 1990s and early 2000s.

At the University of Rochester, the number of women and students from historically marginalized populations has increased from 2010 through 2019 in the incoming first-year undergraduate population. However, studies in higher education have shown that despite equivalent preparation and test scores (GPA, AP, IB, SAT, and ACT) from pre-college study between first-year undergraduate men and women, twice as many men are likely to receive A's in their STEM subjects as women [5-7]. Men are twice as likely as women to repeat classes they have failed [5], while women show a loss in the self-confidence possesed as they enter college that results in lower class participation, lower performance, and lower grades—as early as their first year at college [6-7]. Longitudinal studies have shown the resulting impact can cause women to either transfer out of the major, or, even if they persist and complete, to lack the confidence to pursue advancement and positions of leadership once they enter the workforce [6-7].

Despite the increased efforts to attract women and students from historically marginalized populations to STEM fields in college, curricular development of the skillsets that will help these students succeed and the environment to encourage them through academic struggles are still lacking. The Society of Women Engineers (SWE) reported in 2018 that 32% of women leave STEM degree programs prior to graduation, only 13% of the workforce in engineering are women, and 30% of these women leave the engineering profession within 20 years while citing challenges in their workforce environment as their reason (e.g., having to prove their capabilities repeatedly to their colleagues, etc.) [8-11]. While workforce culture may require an aging-out of senior managers predisposed to accept credentials of incoming young men engineers over equally capable women, the culture of academia has the potential to be more responsive to positive changes.

Standard "chalk-talk" lecture methods which are ubiquitous in higher education do not appeal to all; Berhold et al. have found that women and students from historically marginalized populations, as well as white men, respond positively to diverse educators and methods [12]. Increased engagement with and diversity of role models is important in retaining STEM majors, as well as creating a sense of community and belonging among students. Providing a network that scaffolds not only academic achievement, but also comradery results in classmates and mentors who become lifelong connections and support systems.

Setting up this kind of learning community in a classroom moves away from a lecture-based focus and towards discussions in small groups around exercises and activities. This is the model author Raymond Landis used to teach his Chautauqua Short Course "Enhancing Student Success through a Model Introduction to Engineering Course," which was supplemented by his textbook, *Studying Engineering a Road Map to a Rewarding Career* [1]. Over three decades of teaching, Landis found that appropriate use of various academic success skills was a stronger indicator than intelligence of students' persistence and ultimate success in not only graduating with a degree in engineering, but also in persisting in an engineering career. His book addresses the importance of good study habits, the role of the active student in the classroom, and the need to reflect upon actions and attitudes towards a variety of academic challenges. In the text, he includes the "Academic Success Skills Survey," which is designed to gauge students' perceptions of their own academic success skillsets.

Steffen Peuker, a strong advocate of Landis' ideas, conducted a longitudinal study of students' successful graduation rates following their attendance in a first-year engineering course which exposed them to Landis' model [13]. After attending a short course on the model in 2014 and informed by Peuker's example, one of the authors (Monfredo) developed academic success workshops in a course called "Sustainable Energy" (CHE 150) for first-year chemical engineering students at the University of Rochester (UR). The workshops include activities and reflective essay assignments drawn from Landis' text. Assignments and in-class discussions revolve around a menu of topics that implicate students' emerging identities as engineers and professionals, including:

- personal definitions of success,
- identifying why one aspires to be an engineer,
- exploring how one might solve the National Academy of Engineering (NAE) Grand Challenges,
- understanding the depth of societal contributions made by engineers over the centuries,
- optimizing the knowledge gained and connections made through engineering coursework,
- interacting with upper-level students to gain insights into their success,
- and getting practice with time management and work-life balance for their future careers.

Students are encouraged to visit professors as a part of assignments in the course, and some portion of class time is reserved each semester for UR professionals to share their experiences in STEM fields and raise awareness about available resources for engineering students specifically (e.g., the engineering library, career services, academic tutors, etc.). Classroom activities range from simple and quick team-building exercises (e.g., building towers or bridges from notecards or newsprint, etc.) that provide a low-stakes window into engineering principles and informal opportunities for students to interact all the way to more formal laboratory exercises with assigned teams and peer evaluations. The course culminates in a final open-ended team design project to investigate the iterative nature of engineering design through a solar heating challenge in which students present the struggles they faced and their resulting solutions orally. Together, these assignments and activities aim to enhance the skillsets highlighted by Landis and Peuker as important for students' ultimate success as engineers.

CHE 150 has evolved over the semesters. The course was first offered in the F2015 semester for a total enrollment of 59 students; it included bi-weekly course meetings and most of the

reflective assignments, team projects, guest speakers, and final oral presentations discussed above. Unfortunately, many of the students taking CHE 150 in the F2015 semester were also enrolled in organic chemistry together, and this course conflicted with the academic success workshop, so only 28 students attended the in-person component. The 31 students concurrently enrolled in organic chemistry wrote reflective essays instead to replace those in-person experiences. In the F2016 semester, the academic success workshops moved to being offered weekly, and students received additional machine shop training during the increased contact time. The F2017 semester was unchanged and remained essentially the same as the F2016 semester. The biggest shift occurred between the F2017 semester and the F2018 semester. A new instructor took over, reflective assignments were reduced, more team-building activities were added in the beginning weeks of the semester, a new laboratory exercise was added, projects were modified to include more evidence-based practices and peer evaluation components, and the final oral presentations were expanded to extend over four weeks to accommodate more in-depth discussions and feedback. These changes remained in place in F2019 except for the reduction of reflective assignments, more were added back into the curriculum as a result of encouraging feedback from upperclass students.

Based on the evolution of the course and the ability to begin comparing students' skillsets as seniors to their CHE 150 outcomes (staring with the F2015 cohort who graduated in the S2019 semester), the authors ask the following research questions in this study:

- How does a weekly workshop targeting critical academic success skills for engineers affect students' perceptions of those skills?
- What trends are there in students' perceptions of their post-course skillsets across semesters?
- What academic success skills are not being well-targeted by the weekly workshops?

Methods

To explore changes in students' perceptions of their own academic success skills, CHE 150 students were surveyed using the Academic Success Skills Survey [1] during five consecutive fall semesters (F2015, F2016, F2017, F2018, and F2019). The survey consists of 16 questions about academic success skills which students can respond to on a 5-choice "strongly agree" to "strongly disagree" scale (see Appendix A). In the F2015 semester, the survey was only administered at the end of the course, and the results of the F2015 post-survey are not included here for that reason; however, in all subsequent semesters, the survey was administered once in the first weeks of the course (pre-survey) and once at the end of the course (post-survey) so that changes in students' perceptions could be calculated. To quanyify survey results, responses to specific questions were assigned point values. Responses of "strongly agree" yielded 2 points, "agree" 1 point, "neutral" 0 points, "disagree" -1 points, and "strongly disagree" -2 points, resulting in a possible range of scores from -32 (all "strongly disagree") to 32 (all "strongly agree). Normalized gains between students' pre- and post-survey self-assessments were calculated using the average score for each cohort on each survey by the following formula:

$$NG = (post - pre)/(total\ possible - pre)$$

A normalized gain of 1.0 would mean that students' perceptions changed such that they strongly agreed to all questions to which they had previously responded with less agreement. Students' scores were only included in the cohort averages if they completed both the pre- and post-surveys in a given semester.

Because students are enrolled in multiple courses other than CHE 150 and students' perceptions may change for any number of reasons in their first semester, the course instructor designed a rating system to gauge students' perceptions of how significant the impact of specifically CHE 150 was on their skillset shifts. These rated questions were included on the post-survey only, and their format varied by semester, as seen in Table 1. Because of this variance, direct comparisons between semesters of quantitative results for each academic success skill will not be reported in this manuscript. Instead, general trends in students' post-course perceptions of their skillsets are investigated, which includes skills that might not be adequately targeted by the weekly workshops.

Table 1. Possible responses to "Impact of CHE 150 on this:" by semester

Semester	**Response Format**
F2016	Significant, A bit, None
F2017	Significant Some None 5 4 3 2 1
F2018	N/A (no CHE 150 impact question included)
F2019	A lot, A little, None

The study activities for which the results are reported in this manuscript have been approved by the University of Rochester Internal Review Board (IRB) (F2016-F2018: ID#STUDY00003500, F2019: ID#STUDY00003848).

Results and Discussion

Overall, the pre-post normalized gains indicate that the weekly workshops improved students' perceptions of their academic success skills over the semester, as seen in Table 2. Of particular note are the low pre-survey average score in F2017, the high post-survey average score in F2018, and the relative lack of pre-post change in F2019, which are discussed in more detail below.

Table 2. Pre-post semester academic success skillset normalized gains: F2016-F2019

Semester	**Course Enrollment**	**Response Rate (N)**	**Pre-survey Average Score**	**Post-survey Average Score**	**Pre-Post Semester NG**
F2016	54	81.5% (44)	11.5	15	0.17

F2017	54	88.9% (48)	6.6	11.6	0.20
F2018	60	75.0% (45)	10.3	17.1	0.31
F2019	38	60.5% (23)	13.0	13.7	0.04

In the F2017 semester, pre-survey results suggest that, on average, students only agreed with six or seven of the questions about their academic success skills, although they realized a similar normalized gain when compared to other semesters in the data set. To explore this comparatively low result on the pre-survey, comparison across cohorts (e.g., demographics such as pre-college engineering exposure/coursework, gender, race/ethnicity, incoming GPA, size of incoming class, international status, etc.) are warranted and will be investigated in future studies.

On the other hand, the relatively high post-survey results in the F2018 semester suggest that the changes made between the F2017 and F2018 semesters in the CHE 150 course structure could be contributing positively to students' skillset shifts. However, the course structure remained generally unchanged during the F2019 semester from the F2018 semester, so the low normalized gain for F2019 students brings course structure as a complete explanation for the relatively large gain in F2018 into question. Future work will explore how the individual course assignments and other differences between semesters influence students' perceived skillset shifts.

In terms of the post-course skillset trends, students attributed all changes in their perceptions to CHE 150 to at least some extent. The skill for which changes were least attributed to CHE 150 was managing one's personal life (i.e., "I am effectively managing the various aspects of my personal life, such as interactions with family and friends, personal finances, and outside workload."), but even this skill was perceived to have been impacted by CHE 150 to some extent. In all four semesters, students highlighted positive feelings toward the University of Rochester (i.e., "I feel good about the University of Rochester and about the educational experience I am receiving.") and the perceived importance of setting clear academic goals (i.e., "I recognize the importance of goal setting and I have clear academic goals.") as post-course skills that they agreed most strongly with. On the other hand, students much more weakly agreed (or even disagreed) with statements about their contact with professors (i.e., "I interact regularly with my professors in positive, beneficial ways, both in and out of the classroom."), their preparation before class (i.e., "I prepare for each lecture by reviewing my notes, reading ahead in the text, attempting some problems, and writing down questions."), and their review after class (i.e., I keep up in my classes by mastering the material presented in the last class meeting before the next class meeting."). These skills are vital for success not only in college-level engineering courses, but also in the engineering profession as a whole, and future work will include how the weekly workshops can better target these skills.

Conclusions and Future Directions

In summary, pre-post semester normalized gains of agreement with specific statements about academic success skills indicate that a weekly workshop targeted at improving students' perceptions of those same skills may contribute to positive skillset shifts for future success in engineering. Further, the particular skills that students are most and least likely to agree with

provide direction for future offerings of CHE 150. In particular, while students express positive feelings toward the University of Rochester and agree that they see the importance of setting clear academic goals, they lack follow-through on preparing for their classes and in making strong connections with their professors despite noting at least some impact from CHE 150 on all of the academic success skills included in the survey. Thus, in the F2020 offering of CHE 150, more of the assignments should emphasize interactions with professors and potential mentors as well as the value and practical implementation of preparing well both before and after each class session.

Consideration of the impact of course activities on students' skillsets is an ongoing topic for investigation. As mentioned above in the "Results and Discussion" section, future work will explore how the individual course assignments and differences between semesters influence students' perceived skillset shifts at the individual skill level (rather than as an aggregate score). These comparisons and new data from the F2020 semester will help to further refine the best practices for CHE 150 in regard to improving students' perceptions of their academic success skills. Qualitative data from F2019 (in preparation for a future publication) about students' favorite and least favorite assignments as well as which assignments they found most helpful can be used for triangulation purposes to increase the likelihood that the course will be both valuable and enjoyable for future students. In addition, comparing across cohorts (e.g., demographics such as pre-college engineering exposure/coursework, gender race/ethnicity, incoming GPA, size of incoming class, international status, etc.) can provide context for determining to what extent factors outside of CHE 150 are related to these skillset shifts. With the addition of demographic information, comparisons between men and women, racial/ethnic majority and minority, and international and domestic students may elucidate differential gains for these identity groups. Of particular interest are the potential differences in perception between women on project teams with other women or those on project teams where all the other members are men. All of these topics are in process as future studies and publications.

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Appendix A: Academic Success Skills Survey

1. I interact regularly with my professors in positive, beneficial ways, both in and out of the classroom.
    - Strongly agree
    - Agree
    - Neutral
    - Disagree
    - Strongly disagree
2. I make effective use of my peers by regularly engaging in group study and collaborative learning.
3. I schedule my time, utilizing time and priority management principles.
4. I would give myself an A+ on the amount of time and energy I devote to my studies.
5. I prepare for each lecture by reviewing my notes, reading ahead in the text, attempting some problems, and writing down questions.
6. I keep up in my classes by mastering the material presented in the last class meeting before the next class meeting.
7. I am aware of the importance of being immersed in the academic environment of the institution and spend as much time on campus as possible.
8. I practice good study skills in areas such as note-taking and preparing for and taking tests.
9. I am aware of the best methodologies for reading for comprehension and practice those methodologies during my learning process.

10. I recognize the importance of goal setting and I have clear academic goals.
11. I am effectively managing the various aspects of my personal life, such as interactions with family and friends, personal finances, and outside workload.
12. I am highly motivated through a clear understanding of the rewards graduating in my chosen major will bring to my life.
13. At my university, I know other students in my classes and feel part of an academic learning community.
14. I am aware of and make optimal use of campus resources such as the writing center, counseling center, student health center, library, and career center.
15. I feel good about myself and about my situation, and I am confident about my ability to succeed academically.
16. I feel good about my institution and about the educational experience I am receiving.