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The Redshirt in Engineering Model: Lessons Learned through Implementation Across Six Institutions

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ABSTRACT

There is a critical need to broaden access to engineering education in order to build a strong and diverse engineering workforce. However, four-year engineering programs are typically designed for students who are calculus-ready, so many students who wish to study engineering may need additional preparation and time to succeed. The NSF-funded Redshirt in Engineering Consortium was formed in 2016 to enhance the ability of academically talented but underprepared students from low-income backgrounds to successfully graduate with bachelor's degrees in engineering. The "redshirt" name is derived from the practice of giving some college athletes an extra year of eligibility to prepare for college-level competition. Implementation and evaluation of Redshirt programs across six universities participating in the Redshirt in Engineering Consortium revealed important lessons for schools considering a Redshirt program, including the importance of alignment with a college-wide commitment to increasing equity; sufficient funding for a full-time administrator; ability to fit shared curricular experiences within existing degree requirements; and attention to Redshirt's unique role in the landscape of existing equity programs. Over the course of the five-year grant, understanding of the Redshirt in Engineering Model also evolved to center on five key pillars: (1) a focus on supporting high-achieving students from low income or educationally disadvantaged backgrounds; (2) an expected five-year graduation timeline; (3) personal, professional, and study skills development; (4) intrusive advising; and (5) community-building and social support. This article defines the key elements of the Redshirt in Engineering Model, describes model adaptations and lessons learned through implementation and evaluation across the consortium, and suggests considerations for other institutions interested in implementing a Redshirt in Engineering program.

Key words: undergraduate: first-year, socioeconomic status, equity

INTRODUCTION

For many students from economically disadvantaged backgrounds, a college degree can provide a pathway to upward mobility, particularly in fields like engineering and computer science. However, students from economically disadvantaged backgrounds are underrepresented in engineering and face considerable barriers to degree completion (Lundy-Wagner et al. 2014; Ohland et al. 2012; Engle and Tinto 2008). Such students may be academically talented and perform well in high school, but they are frequently less prepared for college compared to students who attended better-resourced schools (Ennis et al. 2010). The need for an extra year of targeted support for such students inspired the creation of an engineering "Redshirt" program at the University of Colorado Boulder (CU-B) in 2009, with the aim of enhancing the ability of academically talented but underprepared students from low-income backgrounds to successfully graduate with bachelor's degrees in engineering. The name was derived from "redshirting" in college athletics where athletes who show great potential but are under-prepared to compete at the college level are given an extra year to prepare (Ennis et al. 2011). The University of Washington and Washington State University adopted the Redshirt model in 2013. In 2016, the NSF-funded Redshirt in Engineering Consortium was formed to advance the three existing programs and expand the model to three new universities. This article defines the key elements of the Redshirt in Engineering Model, describes model adaptations and lessons learned through implementation and evaluation across six universities, and suggests considerations for other institutions interested in implementing a Redshirt in Engineering program.

The content and structure of the "redshirt year" was guided by research showing the importance of motivated learning, asset mindset, cultural context, active learning, and peer collaboration for improving persistence of engineering students, including those from low-income backgrounds (National Academies of Sciences, Engineering, and Medicine (U.S.) 2018; Ohland et al. 2012; Terenzini et al. 2001; Knight, Carlson, and Sullivan 2007). By fostering a tight-knit community, providing rigorous and responsive academic content, and introducing students to a range of engineering fields and career pathways, the Redshirt Model aims to address the "three dimensions" of engineering learning: accountable disciplinary knowledge, identification, and navigation (Stevens et al. 2008). Development of engineering identity and guidance in navigating the academic enterprise have been found to contribute to persistence (Stevens et al. 2008; Callahan et al. 2014; Adelman 2006). Research also shows the importance of academic support through engineering gateway classes. Callahan and Belcheir (2017) found that starting engineering "calculus-ready" does not predict one-year student retention as well as a student's grade in their first mathematics course. Similarly, Hatfield, Brown, and Topaz (2022) found that receiving low grades (D, F, or Withdraw) in introductory STEM courses leads minoritized women to drop out of STEM at higher rates than White males. For these reasons, Redshirt in Engineering programs emphasize strong mathematics support in the first year, connections with resources to help navigate college life, and community-building. As with redshirting in athletics, the Redshirt in Engineering Model presumes that students are capable of successfully graduating in engineering or computer science, given an extra year of intensive preparation.

In this article, we present evidence of the efficacy of the Redshirt Model as implemented at six universities through the NSF-funded Redshirt in Engineering Consortium. Table 1 illustrates some key differences in institutional context and characteristics of students served by these six programs. Research and evaluation findings have shown that these programs help students develop a strong community of peers; overcome academic barriers to success in STEM courses; strengthen understanding of engineering pathways; and persist in engineering (Knaphus-Soran et al. 2021; Knaphus-Soran, Foster, and Scher 2021; Knight, Louie, and Tsai 2021; Knight et al. 2013; Myers et al. 2018). While this body of research and evaluation indicates that, overall, Redshirt programs are supporting student success in Engineering, there have been variations in the scope and magnitude of outcomes across institutions and over time. An investigation of these variations alongside insights from conversations between consortium members over the past five years have contributed to an emergent understanding of the essential elements of a strong Redshirt in Engineering program and refinement of the model.

Lessons learned from the Redshirt in Engineering Consortium can serve as a roadmap for practitioners hoping to implement similar programs at other institutions. For this reason, this article is organized around around the key elements of the Redshirt in Engineering Model as refined through implementation across the consortium. These elements include (1) a focus on supporting high-achieving students from low income or educationally disadvantaged backgrounds; (2) an expected five-year graduation timeline (including a first-year curriculum focused on mastery of STEM basics); (3) personal, professional, and study skills development; (4) intrusive advising; and (5) community-building and social support (including summer bridge programming).

Table 1. Redshirt in Engineering Programs and Institutional Context.

	CU-B	UW	WSU	BSU	UIUC	UCSD
Institution	University of Colorado, Boulder	University of Washington, Seattle	Washington State University, Pullman	Boise State University	University of Illinois, Urbana-Champaign	University of California, San Diego
Redshirt Program Name	Engineering GoldShirt Program	WA STate Academic RedShirt (STARS)	WA STate Academic RedShirt (STARS)	SAGE Scholars	Academic Redshirt in Science and Engineering (ARISE) Scholars	Academic Community for Engineering Success (ACES)
Year of Inception	2009	2013	2013	2017	2017	2017
Fall 2019[1] Undergrad Eng/CS Enrollments	5,246	5,003	754	1,245	7,129	6,027
# of Redshirt students,[2] 2016–20	219	178	131	75	86	97
% Pell-eligible						
University	16%	22%	25%	25%	23%	NA
Eng/CS	17%	18%	25%	27%	12%	27%
Redshirt	55%	77%	95%	71%	99%	92%
% First Gen[3]						
University	17%	29%	31%	34%	25%	38%
Eng/CS	16%	22%	28%	30%	13%	32%
Redshirt	69%	53%	67%	65%	70%	59%
% URM[4]						
University	18%	16%	24%	19%	19%	25%
Eng/CS	18%	10%	22%	17%	10%	10%
Redshirt	79%	52%	57%	51%	76%	46%
% Women						
University	46%	54%	53%	55%	47%	50%
Eng/CS	30%	31%	16%	20%	24%	25%
Redshirt	30%	42%	29%	35%	37%	51%

1 We are reporting Fall 2019 enrollments rather than more recent data because they are more reflective of the context in which the Redshirt programs were implemented and operated for the five years of the consortium. The COVID-19 pandemic impacted the percentage of students in engineering who are Pell-eligible, a phenomenon indicative of the stratifying effects of the pandemic. Discussion of these impacts is beyond the scope of this paper, though evaluation findings suggest that Redshirt participation helped mitigate the social and economic impacts of the pandemic for students in the 2019 and 2020 cohorts.
2 Though the Redshirt Consortium was established through an NSF S-STEM grant, cohorts are defined by each program and may include students supported through non-NSF funding.
3 For all schools, First Gen refers to students who indicate that neither of their parents has completed a 4-year degree.
4 We use NSF's definition of underrepresented minority (URM), which includes students from racial/ethnic groups historically minoritized in STEM (African American/Black, Hispanic/Latinx/a/o, American Indian/Alaskan Native, Hawaiian/Pacific Islander). This figure is used here as a broad indicator of racial/ethnic diversity within the focal institutions, but we recognize that there is a great deal of variation in both racial/ethnic representation and the experience of students from minoritized groups that is not reflected by this number.

Each section of the article begins with a brief summary describing lessons learned through implementation across the consortium about the Redshirt in Engineering Model's key elements. The narrative that follows describes the key elements in detail, both in terms of the aspirational ideal and on-the-ground implementation across programs. Variations in the amount of institutional support, staffing levels, additional resources/services available for students, college curriculum requirements, and other unique circumstances on each campus have resulted in different challenges and adaptations in implementing each key element (Knaphus-Soran et al. 2018). Relevant findings from evaluation and research are integrated within each section to support our conclusions regarding the implications of these variations and adaptations for the model itself. By examining variation in Redshirt program implementation and lessons learned through the consortium, we hope to inform future efforts to establish Redshirt in Engineering programs and suggest contextual factors that help make Redshirt programs thrive. A summary of our findings is located here: https://engineeringredshirtmodel.carrd.co/.

DATA AND METHODS

Findings regarding the efficacy of Redshirt in Engineering programs described in the sections that follow are drawn from a review of research studies and evaluations conducted over the past decade. Each section presents relevant evidence related to a particular key element of the model. Most of the evidence we rely on is drawn from the University of Washington Center for Evaluation & Research for STEM Equity's mixed-method evaluation of the Redshirt in Engineering Consortium (Knaphus-Soran, Foster, and Scher 2021). We also rely heavily on qualitative research conducted by education scholars at the University of Colorado, Boulder (Knight, Louie, and Tsai 2021).

Redshirt in Engineering Consortium evaluation activities included annual interviews with program administrators; observations of consortium conference calls and other team meetings; analysis of institutional academic data; tracking Redshirt student-level academic performance and retention; and collection and analysis of annual student survey data. Meeting observations and annual interviews with program administrators focused on questions regarding institutional resources and support for the program, program evolution and adaptation, successes and challenges, and consortium-wide exchange of information. Institutional data on degrees, enrollments, and course grades were summarized to provide context and points of reference for examining the academic performance and retention of Redshirt Students.

Annual student surveys conducted as part of the consortium evaluation were sent to all Redshirt students and a comparison group of other students in engineering at each institution. Both groups were asked to complete surveys in the fall of their first year and spring of their first and second years. Baseline and follow-up surveys included questions derived from the program's theory of change, which predicts that holistic support focused on academic preparation, professional development, and social support will increase retention in engineering. Therefore, surveys focused on perceived academic preparedness and ability, engineering identity and certainty, sense of belonging, and career understanding and professionalization as intermediate indicators of success and potential mechanisms contributing to improved retention observed in official academic records. In total, 1249 students completed at least one survey over the course of the five-year grant (544 Redshirt students and 705 non-Redshirt students). Descriptive cross-sectional summaries of survey findings are presented in the body of this paper. Additional findings from statistical analyses of a 976-student subsample for which longitudinal data were available are included in Appendix A.

FINDINGS: KEY ELEMENTS OF THE REDSHIRT IN ENGINEERING MODEL

Key Element #1: Focus on High-Achieving Students from Educationally Disadvantaged Backgrounds

The Redshirt in Engineering programs were created to support students who are high-achieving and motivated to complete a degree in engineering but lack the necessary academic preparation. This population of potential engineering students includes disproportionate numbers of students who are from low-income backgrounds, minoritized racial or ethnic groups, and/or first-generation college students, with substantial overlap among these groups (Engle and Tinto 2008). The six Redshirt in Engineering programs have focused on attracting students with unmet financial need for scholarships and students from groups historically underrepresented in their respective engineering colleges. From 2016-2020 the fraction of Pell-eligible students in the overall engineering student population ranged from 12% to 28% across the six institutions, while the fraction of Pell-eligible Redshirt students ranged from 55% to 99%. Across all schools and years, 62% of Redshirt students were from minoritized racial and ethnic groups, 36% were women, and 77% were Pell-eligible (Knaphus-Soran, Foster, and Scher 2021).

Table 2. Lessons Learned Regarding Redshirt Eligibility and Admissions.

Redshirt students should be:
- Academically high-achieving, as indicated by high school GPA, class rank, and effort to take courses at the highest level offered at their schools.
- Highly motivated to pursue a bachelor's degree in engineering.
- From low-income backgrounds and/or under-resourced schools.

Personal contact is important for recruitment and admission.
- Redshirt staff and students should contact potential Redshirt students directly to describe the purpose and benefits of Redshirt participation.
- Personal essays and/or interviews with potential Redshirt students are important for understanding their educational intentions, expectations, and commitment to engineering.

Redshirt programs should collaborate closely with admissions offices.
- Redshirt programs may be most attractive when they offer an alternate pathway into engineering for students who show promise but would not normally be admitted to engineering.
- Offers for admission to Redshirt programs should coincide with college admissions decisions

Survey findings from the Redshirt Consortium evaluation have consistently shown that Redshirt programs are reaching their intended population. Redshirt students enter college feeling less academically prepared than their peers, but with similar levels of motivation to complete an engineering degree (Knaphus-Soran, Foster, and Scher 2021). Identifying and reaching the ideal Redshirt population involve an intensive and holistic review of academic and non-academic factors, but the exact approach to recruitment and admission varies based on institutional context. At half of the schools (UIUC, CU-B, and UW), Redshirt provides an alternative pathway into engineering for students who were initially admitted to the university but not into the engineering college. Engineering admission is not restricted at the remaining schools (UCSD, BSU, and WSU), but participating in the Redshirt program increases students' chances for success.

For the first three schools, the alternative pathway to admission to engineering helps motivate Redshirt student participation. Identification of students for recruiting requires close coordination among admissions, financial aid, and Redshirt program staff. At CU-B, for example, the admissions office flags potential Redshirt students whose standard metrics are lower than those typically admitted to engineering but have demonstrated an ability to succeed, prioritizing groups who are underrepresented in engineering. The Redshirt team invites these students to apply, conducts interviews, and offers admission to engineering contingent on participation in the Redshirt program. UW adopted a similar approach beginning in 2018 when the College of Engineering changed to a direct-to-college admission policy (in prior years, UW students applied to engineering in their sophomore year and Redshirt participation was incentivized by guaranteed admission to the College). At UIUC, students who apply to engineering majors but have been redirected to the Division of General Studies can apply for the Redshirt program and are brought to campus for a visit/interview. Prospective Redshirt students are offered additional scholarship money before they accept admission to UIUC and are admitted as "Engineering Undeclared" majors.

At BSU, UCSD, and WSU, students are recruited to apply for the Redshirt program after they have been admitted to the College of Engineering. For these programs, determining eligibility criteria and explaining the program's utility to students are more difficult – if students have not been denied admission to the College of Engineering, they may not understand the benefits of the Redshirt program. Eligibility criteria typically include having significant financial need; being members of minoritized racial or ethnic groups or first-generation college students; and/or being behind their peers in terms of academic preparation. Finding the "line" that indicates a need for the program can be challenging. For example, BSU and WSU consider math placement tests as a primary criterion for identifying prospective participants but often have difficulty convincing students they will benefit from the program unless their math scores are extremely low.

At all six institutions, personal contact with Redshirt staff is a critical element of the recruiting process and most schools also include outreach from current Redshirt students. Redshirt staff include families in recruiting events to ensure they can get financial aid and other concerns addressed. This is especially important for families of first-generation college students. Expanding awareness and recognition of the Redshirt programs has also helped with recruitment. At CU-B, for example, awareness has been developed through outreach to targeted high schools and perpetuated through word-of-mouth from successful Redshirt students.

Applicants to Redshirt programs are evaluated on essays and/or interviews in which they describe topics such as their interest and commitment to engineering, challenges they have overcome, and overall motivation and academic potential to succeed. Selection is based on impressions of students' motivation and commitment. Engagement of college faculty in the interview process at CU-B during early years of its Redshirt program helped build support for the program and appreciation for its students.

In summary, Redshirt in Engineering recruitment and admissions processes select students who are motivated to pursue engineering but have faced systemic barriers that would inhibit their success without additional support. By attracting highly-motivated and dedicated students from low-income backgrounds and groups minoritized in engineering, engaging Redshirt staff and students in the recruitment process, connecting with families, and working closely with admissions to identify students who might not otherwise be admitted to Engineering, Redshirt programs can attract students that will contribute to a diverse and excellent engineering workforce.

Key Element #2: Five-Year Graduation Timeline and First-Year Curriculum Focused on the STEM Basics

The inclusion of a performance-enhancing first year and associated expectation that Redshirt students may take five years to complete their bachelor's degree are an integral part of the Redshirt in Engineering Model. The structure of the "Redshirt year" varies across programs but generally includes a structured curriculum, a Redshirt seminar, math and science preparation courses, and

Table 3. Lessons Learned Regarding the First-Year Redshirt Curriculum.

At a minimum, first-year Redshirt curriculum should include:

- A full-year for-credit Redshirt seminar
- Mandatory applied math/project-based introductory engineering course and/or integration of project-based learning into Redshirt instruction
- Redshirt-specific quiz/lab/work group sections for relevant introductory courses
- Structured course plans

Additional academic support elements Redshirt programs have found useful include:

- Mandatory problem-solving workshops
- Structured study sessions
- Introductory Redshirt physics course
- Introductory Redshirt computer science courses

Institutional flexibility is necessary to fully implement the "performance-enhancing year"

- Redshirt programs are most appropriate for institutions without rigid four-year graduation requirements and with flexibility to create Redshirt-specific courses supplemental tutoring or problem-solving sessions. The expectation of a fifth year of study presents an additional financial burden to address. As such, Redshirt programs build scholarship support into the program. In most cases, at least a portion of these funds are disbursed in the second year as an incentive for completing the first-year requirements.

The Redshirt seminar typically includes a focus on personal, professional, and study skills development (described in more detail below) as well as development of strong foundations for academic success in engineering. For most programs, the seminar is either combined with or offered alongside an introductory engineering course designed for Redshirt students. Some programs have incorporated the book *Studying engineering: A roadmap to a rewarding career* by Raymond Landis (Landis 2013) into their seminars and have based engineering math curriculum on the Wright State model. The Wright State model replaces traditional math prerequisite sequences with engineering-specific applied math curriculum, and has been shown to improve performance in engineering courses and graduation rates (Klingbeil and Bourne 2013). At the UW, project-based learning has been incorporated into the introductory Redshirt computer science course, Redshirt math workshops, and the Redshirt seminar. All first-year Redshirt students at CU-B take a hands-on introductory physics course, and some also take an introductory course in engineering problem solving. These configurations depend on the availability of existing courses that align with the Redshirt focus on applied learning.

Most Redshirt programs also include required course sequences and specialized lab, quiz or work group sections associated with foundational math, science, and computer science courses (as relevant). Redshirt students often are not ready for calculus so most start in precalculus. While there are some exceptions for students with strong math placement scores, starting most Redshirt students together in the same precalculus course can bolster math preparation and allow them to move through the first-year curriculum as a cohort. This allows students to develop community in a way that includes built-in informal study groups. Research on the Redshirt Model has also shown that students frequently face challenges when they transition from the supportive first year into the general engineering environment (Knight, Louie, and Tsai 2021). For this reason, some of the Redshirt programs provide additional academic supports into the second year.

Findings from the Redshirt Consortium evaluation suggest that the focus on mastering the STEM basics increases perceived ability in math and science among Redshirt students (Knaphus-Soran, Foster, and Scher 2021). Figure 1 shows that in fall of their first year, Redshirt students rated themselves lower than their peers[1] in math ability, science ability, and ability to apply math and science

[1] Composition of comparison groups varied across institutions. Some were drawn from the Redshirt recruitment list and were Redshirt-eligible students, while others were drawn from the overall population of first-year engineering students. Details about the composition of each comparison group by school are available upon request.

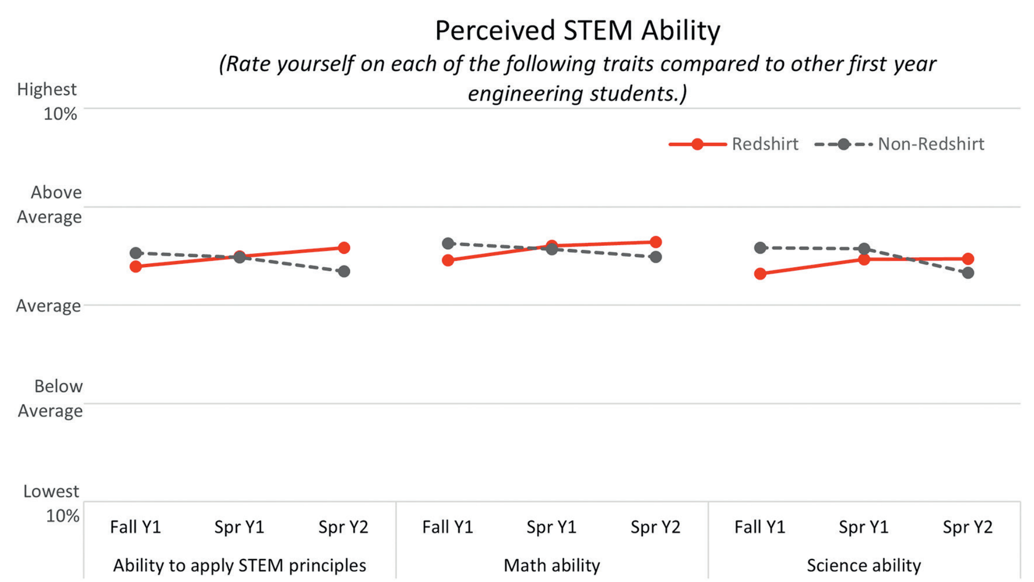

Figure 1. Baseline to Sophomore Change in Perceived STEM Ability.

principles to real-world problems. By the end of their second year, Redshirt students rated themselves higher than non-Redshirt students in all areas. This finding is statistically significant when controlling for institution (see Appendix A).

The evaluation also tracked the average math and science course grades of Redshirt students compared to average course grades in the university overall.[2] Redshirt students consistently outperformed the average student in math and science courses at the UW[3] but less so at the other schools. At CU-B, for example, the first two Redshirt Consortium cohorts outperformed their peers in relevant math courses, but Redshirt grades dropped below their peers in subsequent cohorts when the program was expanded to include students with less math preparation. Likewise, Redshirt students at BSU and WSU were considerably less prepared than the general engineering population (for reasons described in the previous section on Redshirt admissions and recruitment) and did not do as well. While many Redshirt students across the consortium faced challenges in foundational STEM courses, program support helped students persist in engineering. Across all six schools and all cohorts for which there was complete

[2] Lists of specific courses tracked at each institution are available upon request.

[3] Additional multivariate statistical analysis examining the impact of Redshirt participation among students at the UW showed that, on average, Redshirt students' grades in Calculus I and Calculus II were approximately .5 grade points higher than would have been predicted based on a range of academic and background characteristics (Knaphus-Soran et al. 2021).

data,[4] the average 1-year retention in engineering was 89%, 2-year retention was 75%, and 3-year retention was 70% (Knaphus-Soran, Foster, and Scher 2021). These retention rates are exceptionally high, given that average 1-year retention in engineering among most groups is around 80% (ASEE 2017).

While the five-year graduation expectation and associated first-year curriculum are central to the Redshirt Model, this component has been difficult for some programs to implement. For example, rigid four-year graduation requirements at UCSD have prevented the Redshirt program from offering the Redshirt seminar as a for-credit course; made it difficult for students to take classes together as a cohort; and prohibited a five-year program. This limitation has been offset somewhat by a five-week, six-credit, Summer Engineering Institute prior to the first year, a weekly not-for-credit Redshirt discussion group, and priority access to tutoring. Similarly, institutional constraints prevented the Boise State SAGE program from creating dedicated Redshirt labs/quiz sections. Due to these constraints, UCSD and BSU Redshirt programs were not fully aligned with the Redshirt Model.

In summary, lessons learned from across the Redshirt in Engineering Consortium suggest that Redshirt programs are most successful at improving perceived skills and performance in foundational STEM courses when they establish a five-year graduation timeline that begins with precalculus; create a for-credit Redshirt seminar; have dedicated lab/quiz sections for Redshirt students; and provide structured tutoring and study sessions. UW and CU-B Redshirt students have also benefited from additional Redshirt-specific STEM workshops and courses, as indicated by greater academic performance for Redshirt students relative to their peers at these schools.

Key Element #3: Personal, Professional, and Study Skills Development

In addition to math and science coursework, Redshirt students take courses that provide research-informed practices for developing study and learning skills, help them navigate

Table 4. Lessons Learned Regarding Personal, Professional, and Study Skills Development.

Redshirt seminars and/or supplemental courses should focus on:
- Learning and study skills
- Career exploration
- Professional development
- Personal well-being and mindfulness

Redshirt programs should collaborate with faculty and engineering professionals
- Faculty and engineering professionals should be invited to present in Redshirt seminars
- Students should be encouraged to meet one-on-one with faculty through mentorship pairings and/or class assignments
- Group mentorship meetings are less intimidating for students in the first year; there tends to be greater engagement if one-on-one mentorship pairings are established at the end of the first year/beginning of the second year

[4] 1-year retention includes 4 cohorts of students at UW, WSU, and CU-B and 3 cohorts of students at BSU, UCSD, and UIUC. 2-year retention includes 3 cohorts of students at UW, WSU, and CU-B and 2 cohorts of students at BSU, UCSD, and UIUC. 3-year retention includes 2 cohorts of student at UW, WSU, and CU-B and 1 cohort of students at BSU, UCSD, and UIUC.

university resources, offer career and professional development, and enhance metacognitive skills such as mindfulness and resilience. Most programs deliver personal, professional, and study skills development curriculum during the first-year Redshirt seminar. This seminar offers a space for students to reflect on their learning and educational experiences; brainstorm strategies for self-improvement; develop schedules to improve time management and study skills; develop resumes and cover letters; and learn other aspects of professionalism. The seminar also provides an overview of non-Redshirt university resources such as college of engineering community and career centers, health and wellness services, counseling services, and writing and tutoring centers.

Several programs invite faculty to present at seminars and/or give students an assignment to interview a faculty member. Engineering faculty and professionals introduce students to engineering majors and career pathways and provide professional planning and support. These interactions also help faculty gain appreciation for the talents and perspectives Redshirt students bring. Most Redshirt programs also have a faculty mentor program, though program administrators have consistently reported challenges related to encouraging/incentivizing students and faculty mentors to meet with each other (Knaphus-Soran, Foster, and Scher 2021). Over the past five years, all programs have adapted their approach to mentorship to facilitate greater engagement between students and mentors. For example, programs have found that pairing students with a faculty mentor at the end of their first year or beginning of their second year led to stronger mentorship relationships. Some programs have had more success with group mentorship rather than one-on-one mentorship, and in tracking the frequency of student-mentor interactions. Often Redshirt staff must schedule the mentoring meetings. Typically, Redshirt staff facilitate initial networking events between students and mentors. Faculty are encouraged to include their participation as mentors in their academic personnel files as contributions to diversity, equity, and inclusion. Across the different programs, the number of required mentoring meetings ranges from one to five times per term. In mentoring meetings, students and mentors are encouraged to discuss career choices, focus areas within the major, and undergraduate research.

Results from the Redshirt Consortium Evaluation show that Redshirt students saw a gain in critical thinking, interpersonal skills (including leadership ability, communication skills, and networking ability), resume writing, self-confidence, and time management in their first two years, while non-Redshirt students' ratings declined in all areas except resume writing (See Figure 2). This association is statistically significant in all domains except interpersonal skills. Effects varied somewhat from school to school – there is some indication that the UW Redshirt program has more of an effect on academic abilities, self-confidence, and study skills; the UIUC program

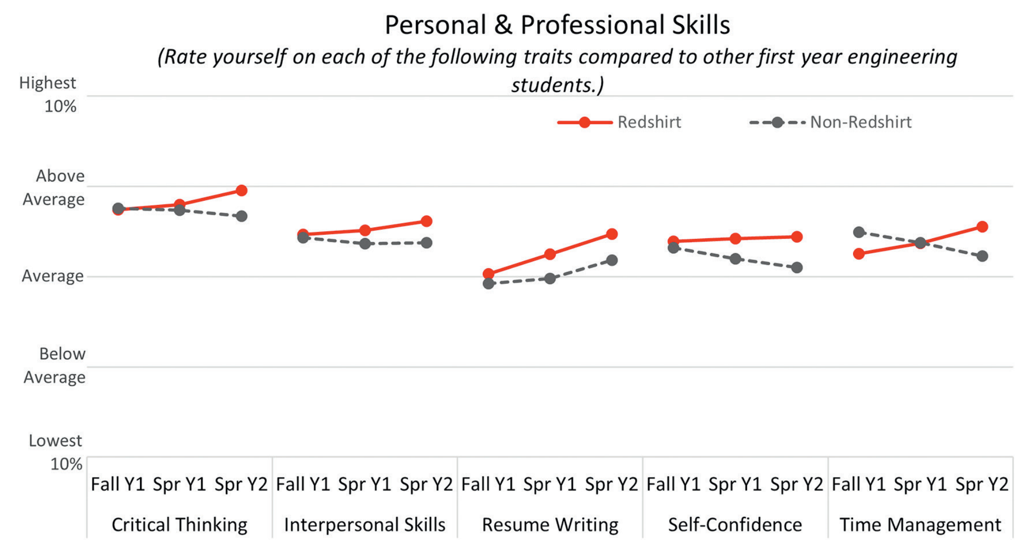

Figure 2. Baseline to Sophomore Change in Personal & Professional Skills.

has more of an effect on self-confidence and professional development; UCSD has more of an impact on professional development; and CU-B and BSU have more of an impact on team-building (Knaphus-Soran, Foster, and Scher 2021). See Appendix A for a survey analysis summary.

Redshirt participation also had an impact on career certainty and understanding; Redshirt students were more intent than non-Redshirt students on engineering or computer science for their degree and career choice. Non-Redshirt students reported more exposure to engineering or computer science through interpersonal relationships and independent research, but by their second year, Redshirt students had a greater understanding of engineering career pathways. The association between Redshirt participation and career understanding was statistically significant, and this association was particularly strong at the UW and UCSD (see Appendix A for a summary of variation in survey findings across institutions). Figure 3 shows change in career certainty and understanding for Redshirt and non-Redshirt students among the five cohorts Consortium-wide (Knaphus-Soran, Foster, and Scher 2021).

In summary, the Redshirt focus on developing personal, professional, and study skills in addition to academic skills has had a notable effect on participants. In particular, Redshirt students are buffered from the decrease in perceived self-confidence, time management ability, and critical thinking ability seen among other first and second year engineering students. This is a result of a strong focus on study skills, professional skills, and career development in Redshirt seminars and through connection with engineering faculty.

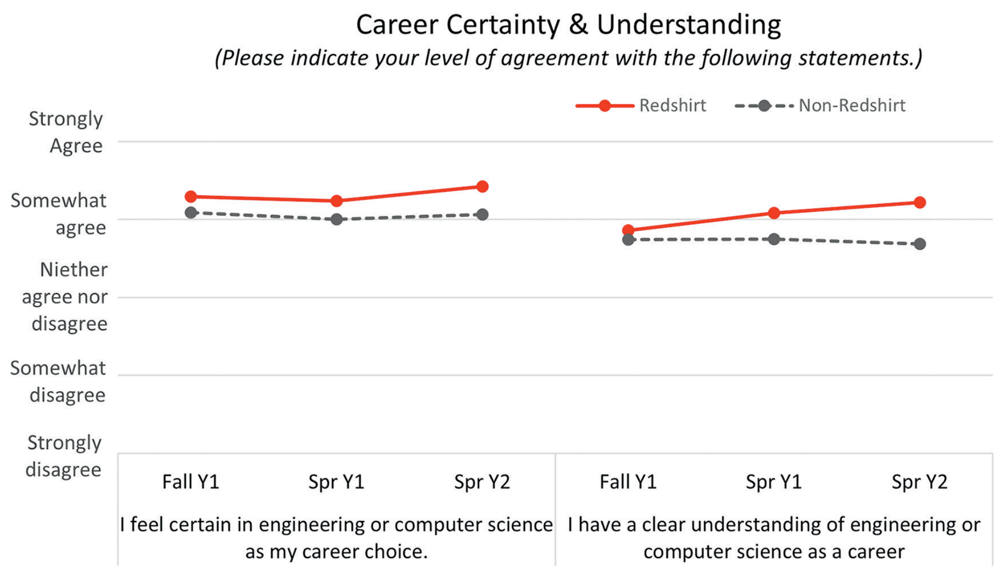

Figure 3. Baseline to Sophomore Change in Career Certainty and Understanding.

Key Element #4: Intrusive Advising

Intrusive advising goes beyond the regular levels and types of advising provided to engineering students at each institution. Redshirt advising generally includes at least two required meetings per term and more as needed. These meetings focus on grade checks and discussion of study habits and may include input from instructors and teaching assistants. For this reason, Redshirt advisers should maintain close relationships with instructors of prerequisite courses. At UW and CU-B, there are dedicated Redshirt instructors in addition to general math, chemistry, and computer science faculty who work closely with the Redshirt advisers to ensure individual and cohort success. This intrusive/proactive approach motivates students to seek help at the first indication of academic difficulty (Earl 1988; Ohrablo 2018; Dobrinich Johns, Sasso, and Puchner 2017).

Table 5. Lessons Learned Regarding Intrusive Advising.

Redshirt advising includes:
- Frequent meetings with students (at least 2 per quarter or 4 per semester)
- Regular monitoring of student grades
- Support for community-building and social events
- Close coordination between Redshirt advisers and prerequisite instructors

Intrusive advising requires institutional commitment
- Intrusive advising is resource-intensive, and thus requires institutional commitment to support staff time

In most Redshirt programs, advisers also serve as the instructor for the Redshirt seminar and/or supplemental math course. As described in the previous section, these first-year skills courses often include activities that assist students in identifying challenges and learning to ask for help. The intentional and frequent contact between Redshirt students and advisers helps develop a caring and beneficial relationship that can lead to increased academic motivation and persistence (Varney 2012). Intrusive advising strategies are beneficial when working with students from racial/ethnic/gender groups minoritized in engineering, academically underprepared students, students from low-income backgrounds, students with disabilities, and probationary students (Heisserer and Parette 2002).

In Redshirt programs, intrusive advising means leveraging any and all institutional resources to help students succeed. The advisers give considerable thought to what this may look like for each cohort and individual student. Advisers find many ways to make themselves accessible to students; they may have open-door policies, walk students across campus to connect them with resources, attend campus events with students, convene social gatherings and online community events, and have informal virtual drop-in hours. Full implementation of intrusive advising is difficult at less-resourced institutions, but all programs provide as much support as possible. For example, UCSD, BSU, and WSU Redshirt programs have all been run by part-time rather than full-time administrators. WSU has partnered with a general engineering adviser to provide extra advising support but could not match the extent of contact offered at UW, CU-B and UIUC. Similarly, UCSD's part-time Redshirt adviser held weekly discussion groups, small group advising, and facilitated faculty mentor pairings to complement major advising.

The extent to which intrusive advising can be adopted greatly depends on institutional context and resources. In the case of the two most-resourced programs (CU-B and UW), the Redshirt adviser could provide extensive holistic support through the first two years. As an example, UW Redshirt students must report grades on quizzes and homework in addition to midterms and finals. While final grade checks are conducted at several institutions up to graduation, these are typically more informal. At UW and CU-Boulder, however, a student in any year may be encouraged to meet with the Redshirt adviser and guided towards necessary support services.

Effective intrusive advisers must be attuned to the needs of each student, be committed to student care and engagement, and coordinate support with faculty and other institutional administrators. Many Redshirt advisers continue to support students beyond the first year, either formally or informally (Knight, Louie, and Tsai 2021). Intrusive advising requires a significant amount of time and effort, particularly for students who struggle the most. According to Tsai et al., the high-touch access model of Redshirt programs creates a supportive environment whereby students are preserved "as whole people within these reductionist, mechanistic environments of large scale undergraduate engineering education" (Tsai et al. 2017, 1).

Key Element #5: Community-Building and Social Support

Table 6. Lessons Learned Regarding Community-Building and Social Support.

At a minimum, Redshirt programs should:
- Offer a summer bridge program that includes academic support to ease students into rigorous engineering coursework; a shared residential experience; and community-building activities
- Hold social events
  - at least once per quarter or twice per semester
  - for both individual cohorts and across cohorts

If possible, Redshirt programs should:
- Offer co-housing for Redshirt students
- Implement peer mentorship programs

Building community among Redshirt students and establishing a social support network are integral parts of the Redshirt Model due to their impact on belonging, identity, and academic success (Strayhorn 2019; Godbole et al. 2018; Leydens, Morgan, and Lucena 2017; Benedict et al. 2018; Gattis, Hill, and Lachowsky 2007; Marra et al. 2010). Across Redshirt programs, this is achieved primarily through summer bridge programs and social events. Several Redshirt institutions also have peer mentorship programs and co-house Redshirt students. Students responding to the annual evaluation survey consistently report that the tight-knit Redshirt community most impacted their experience; some even describe their Redshirt cohort as a family.

Summer bridge programs (SBPs) look different across each of the six Redshirt institutions, but all help students bond with peers, get a jump start on their academics, become familiar with campus resources, and begin to see themselves as engineers. UCSD offers the longest SBP with a 5-week residential program that includes for-credit courses, office hours, lab hours, and tutoring sessions. CU-B's 2-week SBP also offers for-credit courses, including an innovative engineering design and spatial visualization course (Ennis and Myers 2019). Other programs emphasize academic preparation by assigning summer homework, providing hands-on STEM-focused activities, and/or familiarizing students with the campus. SBPs at all schools focus on community-building; for instance, BSU's SBP includes a three-day rafting trip that helps students bond over a unique shared experience (Salzman et al. 2019). Most SPBs utilize older Redshirt students as peer mentors who live in the dorms with students, serve as tutors, and host social activities (Ennis and Myers 2019; Salzman et al. 2020). SBPs are generally funded by the college/university and grant funds, but some programs receive private gifts or state funding. Programs have also collaborated on SBPs with other campus programs, such as the Louis Stokes Alliance for Minority Participation (LSAMP) at BSU and WSU, and the IDEA Engineering Student Center at UCSD.

All Redshirt programs hold social events throughout the year. Some popular events include UW's annual Bowling with the STARS event, UCSD's Pool, Ping Pong, and Pizza Night, and tie dye parties at BSU. Social events were made more difficult by the COVID-19 pandemic, but programs maintained a commitment to community-building through events like virtual game nights. Events for single cohorts allow students to build a close social support network, and events for all Redshirt students allow students to connect with students at different points in their academic careers for near-peer connection and mentorship.

Several schools require or encourage Redshirt students to live together for their first one or two years in engineering-focused living learning communities or general student housing. Having all Redshirt students living together facilitates the delivery of academic support services and social activities. However, some schools have not been able to provide joint housing due to institutional constraints. At UCSD, for example, the division of the university into seven residential colleges with seven sets of general education requirements means that requiring students to be housed together would also remove their flexibility in choosing among the sets of general education requirements.

Several Redshirt programs have established peer mentorship programs which pair incoming students with former Redshirt students and provide cross-cohort group activities such as study sessions, professional development, and/or social activities. UCSD and UIUC provide incentives for peer mentors and first-year students to participate in activities together to increase engagement. UIUC also developed a class for first- and second-year students to take together that focused on building mentorship relationships with each other and with faculty.

Qualitative research on the experience of Redshirt students across the consortium reveals that Redshirt programs help build community and provide students with a lasting community of friends beyond their first year (Knight, Louie, and Tsai 2021; Salzman et al. 2020; Knaphus-Soran et al. 2021). Research on the experience of Redshirt students beyond the first year suggests that it can be difficult to fit in with other engineering peers when students move from the close-knit Redshirt environment into the general engineering community (Knight, Louie, and Tsai 2021). As shown in Figure 4, this is

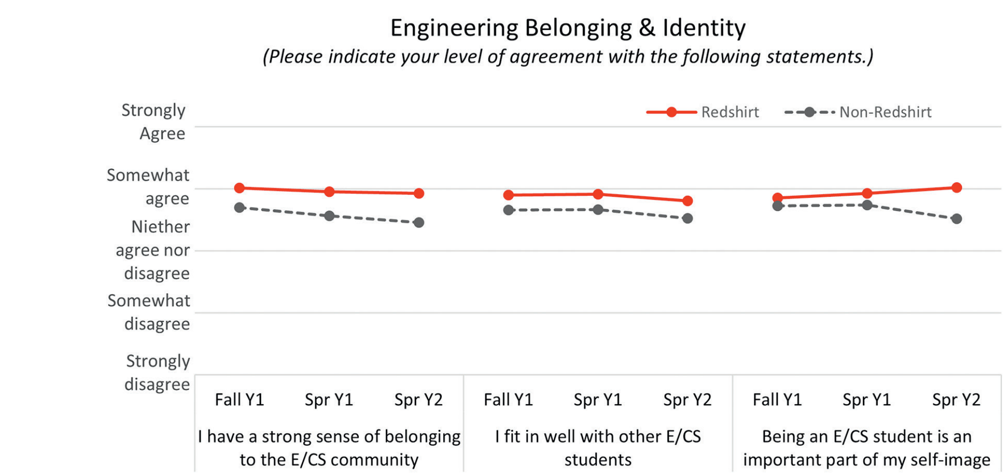

Figure 4. Baseline to Sophomore Change in Engineering Belonging and Identity.

not unique to Redshirt students; sense of belonging in engineering more broadly declines for both Redshirt and non-Redshirt students following their first year. However, there is some indication that Redshirt participation contributes to increased engineering identity, particularly at CU-B.

In summary, Redshirt programs provide tight-knit communities for students that provide them with social support beyond the first year. This support is developed through community-building activities both within and between cohorts that build off the foundation of strong summer bridge programming.

DISCUSSION

This article has provided a roadmap for successful implementation of a Redshirt in Engineering program informed by lessons learned through the Redshirt in Engineering Consortium. Research and evaluation of Redshirt in Engineering programs indicate that the model is a promising intervention to improve the engineering experience and increase retention among students from low-income and educationally disadvantaged backgrounds. Redshirt programs provide students with strong mentorship and guidance, a supportive community of peers, introduction to the field of Engineering, resources for navigating college, and academic support to increase chances of early academic success. This multi-dimensional approach addresses several factors known to improve retention in engineering (Stevens et al. 2008; Callahan et al. 2014; Adelman 2006; Callahan and Belcheir 2017; Engle and Tinto 2008; Dobrinich Johns, Sasso, and Puchner 2017). With support from Redshirt programs, students from less privileged backgrounds can graduate in engineering or computer science and possibly change their family's socioeconomic status in one generation. However, these programs are inherently resource-intensive and require substantial institutional commitment and flexibility to be implemented in alignment with the Redshirt Model.

The most robust Redshirt programs have been sustained as a result of institutional resources including budget allocations, support from fundraising personnel, and faculty time to write proposals to funding agencies. Programs without funding for full-time program coordinators and/or dedicated Redshirt advisers have a harder time providing holistic support. Established programs have also had the autonomy to establish their own Redshirt-specific courses, lab sections, workshops, and second-year programming that create an expected five-year graduation timeline. Some programs have also found that the scope of Redshirt-specific programming can be adapted based on the availability of other complementary and mutually-reinforcing services on campus. Redshirt programs can benefit from being part of larger entities such as educational opportunity programs or learning centers that help leverage support and connections with other services across campus (Muraskin 1997). For example, the Redshirt program at CU-B benefits from being housed within the Broadening Opportunity through Leadership and Diversity (BOLD) Center in the College of Engineering which provides considerable administrative and programmatic support.

The level of support required to implement a high-fidelity Redshirt in Engineering program with a full five-year curriculum requires institutional commitment to improving diversity, equity, and inclusion in engineering and computer science. Additionally, Redshirt programs may be more attractive to students from disadvantaged backgrounds when they provide an alternative pathway into engineering and provide support to ease the financial burden of the extra time to degree. For these reasons, Redshirt programs may be particularly well-suited for schools with a strong commitment to increasing diversity and reducing disparities between the percentage of Pell-eligible students in the overall student body and in the engineering college. While Redshirt programs are cost-intensive, they can offer an important pathway to engineering degree completion for their focal student populations and in so doing help increase diversity in the engineering and computer science fields.

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APPENDIX A: SURVEY ANALYSIS

Below is a summary of responses the baseline, spring and sophomore surveys administered to all Redshirt cohorts and a sample[5] of non-Redshirt first-year students in engineering at all six institutions as part of the Redshirt in Engineering Consortium Evaluation (Knaphus-Soran, Foster, and Scher 2021). Table 7 displays the average academic preparedness for STEM courses, and change between fall and spring of freshman year, and between fall of freshman year and spring of sophomore year. Overall, the magnitude of the change was larger for Redshirt students than non-Redshirt students across the board. An analysis of covariance (ANCOVA) was conducted

Table 7. Average STEM Preparedness for Redshirt and non-Redshirt Students in Fall Y1, Spring Y1, and Spring Y2.

	Redshirt			Non-Redshirt		
Subject	FY1	SY1 (SY1-FY1)	SY2 (SY2-FY1)	FY1	SY1 (SY1-FY1)	SY2 (SY2-FY1)
Calculus	3.55	3.96(0.41)	4.21(0.66)	3.99	4.11(0.12)	4.26(0.27)
Chemistry*	3.08	3.37(0.29)	3.56(0.48)	3.34	3.39(0.05)	3.56(0.22)
Computing	2.79	2.92(0.13)	3.71(0.92)	3.13	3.33(0.2)	3.35(0.22)
Physics	3.00	3.07(0.07)	3.29(0.29)	3.37	3.39(0.02)	3.48(0.11)

Rating Scale: 1 = "Very unprepared," 2 = "Unprepared," 3 = "Somewhat prepared," 4 = "Prepared," 5 = "Highly prepared"
Statistical significance levels based on ANCOVA results from a subset of the total sample: *=p<0.05, **= p<0.01, ***= p<0.001

[5] The composition of the non-Redshirt sample varies from institution to institution – at some schools the survey is sent to all first-year engineering students, at others it is sent to Redshirt-eligible students only. Information on sample composition by school is available upon request.

with a subset of 976 students who completed both the fall and spring surveys in their first year to determine whether differences between Redshirt and non-Redshirt students in the change in preparedness from fall to spring across academic subjects was statistically significant. Findings indicate that, when controlling for institution, the association between Redshirt participation and growth in preparedness was statistically significant for chemistry, $F(1,829)=6.79$, $p<.05$, but not for calculus, computing, or physics.

Analysis of variance (ANOVA) analyses by institution show that associations between Redshirt participation and growth in academic preparedness were statistically significant at UW for Calculus and Chemistry and UIUC for Chemistry. At UCSD, Redshirt participation was associated with a significantly smaller gain in preparedness for Chemistry. Table 8 displays a summary of preparedness ANOVA findings by school.

Table 8. Preparedness ANOVA Findings by School.

	UW	WSU	CU-B	BSU	UIUC	UCSD
Calculus	$F(1,187)=24.2$, $p<.001$	NS	NS	NS	NS	$F(1,341)=8.16$, $p<.01$ (negative association)
Chemistry	$F(1,186)=8.9$, $p<.01$	NS	NS	NS	$F(1,114)=4.94$, $p<.05$	NS
Computing	NS	NS		NS	NS	NS
Physics	NS	NS		NS	NS	NS

Note: table includes the f-value for the effect of Redshirt and associated p-value (level of statistical significance). "NS" = not significant.

Table 9 displays the average general self-confidence and perceived ability across a range of academic and professional domains reported by Redshirt and non-Redshirt students, and change between fall and spring of freshman year, and between fall of freshman year and spring of sophomore year. Overall, Redshirt students saw a gain in self-confidence and domain-specific abilities while non-Redshirt students' self-confidence and perceived abilities declined. An analysis of covariance (ANCOVA) was conducted with a subset of 976 students who completed both the fall and spring surveys in their first year to determine whether the difference between Redshirt and non-Redshirt students in the change from fall to spring across confidence and abilities was statistically significant when controlling for institution. Our findings indicate that, when controlling for institution, the association between Redshirt participation and growth in self-confidence and domain-specific abilities were statistically significant Consortium-wide in all areas aside from leadership ability, communication skills, and networking ability.

Table 9. Average Perceived Ability for Redshirt and non-Redshirt Students in Fall Y1, Spring Y1, and Spring Y2.

	Redshirt			Non-Redshirt		
	FY1	SY1 (SY1–FY1)	SY2 (SY2–FY1)	FY1	SY1 (SY1–FY1)	SY2 (SY2–FY1)
Self-confidence**	3.39	3.43(0.04)	3.44(0.05)	3.32	3.2(–0.12)	3.1(–0.22)
Leadership ability	3.60	3.64(0.04)	3.75(0.15)	3.62	3.57(–0.05)	3.62(0)
Math ability**	3.46	3.6(0.14)	3.64(0.18)	3.63	3.57(–0.06)	3.49(–0.14)
Science ability***	3.33	3.47(0.14)	3.47(0.14)	3.58	3.56(–0.02)	3.33(–0.25)
Communication skills	3.49	3.59(0.1)	3.74(0.25)	3.56	3.58(0.02)	3.74(0.18)
Apply math & sci principles**	3.39	3.5(0.11)	3.58(0.19)	3.53	3.48(–0.05)	3.34(–0.19)
Ability to perform in teams	3.95	3.91(–0.04)	3.92(–0.03)	3.88	3.84(–0.04)	3.9(0.02)
Critical thinking**	3.74	3.79(0.05)	3.96(0.22)	3.76	3.74(–0.02)	3.67(–0.09)
Time management**	3.25	3.38(0.13)	3.55(0.3)	3.49	3.37(–0.12)	3.23(–0.26)
Networking	3.26	3.25(–0.01)	3.47(0.21)	3.08	2.98(–0.1)	2.88(–0.2)
Resume writing***	3.04	3.25(0.21)	3.47(0.43)	2.92	2.98(0.06)	3.18(0.26)
Interview skills*	3.24	3.29(0.05)	3.39(0.15)	3.06	3.06(0)	3(–0.06)
Interpersonal skills (composite of leadership, communication, teams, networking, and interview skills)	3.47	3.51(.04)	3.61(.14)	3.43	3.37(–0.07)	3.38(–0.05)

Rating Scale: 1 = “Lowest 10%,” 2 = “Below Average,” 3 = “Average,” 4 = “Above Average,” 5 = “Highest 10%”
Statistical significance levels based on ANCOVA results from a subset of the total sample: *=p<0.05, **= p<0.01, ***= p<0.001

Further analysis of variance (ANOVA) analyses by institution reveal that the association between Redshirt participation and growth in self-confidence was statistically significant at UW and UIUC; math and science ability, ability to apply math and science principles to real world problems, and critical thinking skills were statistically significant at UW; ability to perform in teams was statistically significant at CU-B and BSU; time management was statistically significant at UW; resume writing was statistically significant at UW, UIUC, and UCSD; and interview skills was statistically significant at UCSD. Table 10 displays a summary of ANOVA findings for self-confidence and ability by school.

Table 11 displays the average feelings of engineering belonging, self-image, fitting in, career certainty, and career knowledge, and change between fall and spring of freshman year, and between fall of freshman year and spring of sophomore year. Overall, the magnitude of the change was larger for Redshirt students than non-Redshirt students across the board. An analysis of covariance (ANCOVA) was conducted with a subset of 976 students who completed both the fall and spring surveys in their first year to determine whether differences between Redshirt and

Table 10. Self-Confidence and Domain-Specific Perceived Ability ANOVA Findings by School.

	UW	WSU	CU-B	BSU	UIUC	UCSD
Self-confidence	F(1,187)=4.8, p<.05	NS	NS	NS	F(1,114)=4.66, p<.05	NS
Leadership ability	NS	NS	NS	NS	NS	F(1,338)=5.26, p<.05
Math ability	F(1,187)=15.9, p<.001	NS	NS	NS	NS	NS
Science ability	F(1,185)=22.55, p<.001	NS	NS	NS	NS	NS
Communication skills	NS	NS	NS	NS	NS	NS
Apply math & science principles	F(1,186)=17.98, p<.001	NS	NS	NS	NS	NS
Ability to perform in teams	NS	NS	F(1,68)=8.65, p<.01	F(1,48)=6.9, p<.05	NS	NS
Critical thinking	F(1,187)=8.68, p<.01	NS	NS	NS	NS	NS
Time management	F(1,185)=19.8, p<.001	NS	Data not available	NS	NS	NS
Networking	NS	NS	NS	NS	NS	NS
Resume writing	F(1,186)=6.1, p<.05	NS	NS	NS	F(1,114)=4.89, p<.05	F(1,338)=4.62, p<.05
Interview skills	NS	NS	NS	NS	NS	F(1,338)=4.17, p<.05

Note: table includes the f-value for the effect of Redshirt and associated p-value (level of statistical significance). “NS” = not significant.

Table 11. Average Engineering Belonging and Career Knowledge for Redshirt and non-Redshirt Students in Fall Y1, Spring Y1, and Spring Y2.

	Redshirt			Non-Redshirt		
	FY1	SY1 (SY1–FY1)	SY2 (SY2–FY1)	FY1	SY1 (SY1–FY1)	SY2 (SY2–FY1)
I have a strong sense of belonging to the engr or cs community	4.01	3.96(–0.05)	3.92(–0.09)	3.70	3.57(–0.13)	3.48(–0.22)
In general, being an engineering or cs student is an important part of my self-image	3.85	3.93(0.08)	4.02(0.17)	3.72	3.74(0.02)	3.54(–0.18)
I fit in well with other engr or cs students	3.89	3.92(0.03)	3.79(–0.1)	3.66	3.66(0)	3.55(–0.11)
I feel certain in engr or cs as my career choice	4.30	4.24(–0.06)	4.42(0.12)	4.08	4(-0.08)	4.08(0)
I have a clear understanding of engr or cs as a career **	3.86	4.1(0.24)	4.21(0.35)	3.74	3.74(0)	3.71(–0.03)

Rating Scale: 1 = “Strongly disagree,” 2 = “Somewhat disagree,” 3 = “Neither agree nor disagree,” 4 = “Somewhat agree,” 5 = “Strongly agree”

Statistical significance levels based on ANCOVA results from a subset of the total sample: *=p<0.05, **= p<0.01, ***= p<0.001

non-Redshirt students in the change in engineering belonging and knowledge from fall to spring across academic subjects was statistically significant. Our findings indicate that, when controlling for institution, the association between Redshirt participation and change over students' first year was only statistically significant for understanding of engineering or computer science as a career choice $F(1,820)=9.33$, $p<.01$.

Further analysis of variance (ANOVA) analyses by institution reveal that the association between Redshirt participation and growth in engineering self-image was statistically significant for CU-B, and growth in engineering/cs career understanding was statistically significant at UW and UCSD. Table 12 displays a summary of ANOVA findings for engineering belonging, self-image, and career certainty and understanding by school.

Table 12. Engineering Belonging and Career Knowledge ANOVA Findings by School.

	UW	WSU	CU-B	BSU	UIUC	UCSD
Sense of belonging to engr	NS	NS	NS	NS	NS	NS
Engr part of self-image	NS	NS	F(1,67)=13.35, p<.05	NS	NS	NS
Fit in with engr students	NS	NS	NS	NS	NS	NS
Engr career certainty	NS	NS	NS	NS	NS	NS
Engr career understanding	F(1,185)=4.16, p<.05	NS	NS	NS	NS	F(1,338)=5.04, p<.05

Note: table includes the f-value for the effect of Redshirt and associated p-value (level of statistical significance).
"NS" = not significant.