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Using Early Introduction to Research to Increase STEM Majors: A Tale of two Colleges, one small highly selective private and one non-selective regional public.

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This paper outlines a very successful intervention that has increased the number of STEM (Science, Technology, Engineering, and Mathematics) majors in general, and chemistry majors in particular, at two primarily undergraduate institutions. The intervention, early introduction to research and supplemental programming for incoming first year students, increased retention and graduation rates at both institutions. The results were particularly spectacular at Armstrong State University.

INTRODUCTION – A TALE OF TWO COLLEGES

Hamilton College is a highly selective liberal arts college located in central New York. The 2015-16 Common Data Set reveals that as of the 2015-16 academic year it had 1862 full-time and 10 part-time students, with 63.4% of its undergraduates reported as white and 51.3% female. The largest ethnic populations reported were Race and/or ethnicity unknown at 7.7%, Asian at 7.5%, and Hispanic/Latino at 7.4%. The six-year graduation rate for the cohort that entered college in the Fall of 2009 was 92%. The acceptance rate for first-time, first-year undergraduates in the Fall of 2015 was 24.8%, and the yield rate was 35.1%. The 25th percentile for Critical Reading SAT scores was 650 and the 75th percentile was 740, while the corresponding scores for Math SAT scores were 650 and 730. Total tuition and fees were $51,240 with a total cost of attendance listed as $64,250 before allocation of financial aid. During the 2015-16 academic year, 47.8% of the undergraduates received financial aid and 100% of financial need was fully met. The average need-based financial award was $45,553, and the average loan was $4,234. The college has 189 full-time and 43 part-time faculty, and a student/faculty ratio of 9:1. In 1998-99 the chemistry faculty at Hamilton made a concerted effort to ramp up their undergraduate research program. A senior thesis research project is required for graduation, and the chemistry faculty typically worked with four or five students each during the summer and academic year. During the time period of this project, the seven faculty often worked with a total of 35-40 students during the summer. The college supported at least two students per faculty member each summer, and oftentimes more, and all faculty had external research grants from Research Corporation, Dreyfus Foundation, ACS/PRF, NSF, and NIH during this time period.

Armstrong State University is a primarily undergraduate institution and a member of the University System of Georgia. The College of Science and Technology (CST) was created in 2008, from existing colleges of liberal arts and a school of computing. The 2015-16 Common Data Set reveals that as of the 2015-16 academic year it had 4650 full-time and 1681 part-time
students, with another 772 students enrolled in master’s programs. Of the 6331 undergraduates, 56.9% were reported as white and 66.4% were female. The largest ethnic populations were Black/African-American at 24.8% and Hispanic/Latino at 7.1%. The six-year graduation rate for the cohort that entered college in the Fall of 2009 was 33.0%. The acceptance rate for first-time, first-year undergraduates in the Fall of 2015 was 74.6%, and the yield was 56.9%. The 25th percentile for Critical Reading SAT scores was 460 and the 75th percentile was 550, while the corresponding scores for Math SAT scores were 450 and 530. Total tuition and fees for in-state students were $6,332. Housing is available for 1000 students and for those students, total fees including room, board, tuition and fees was $16,830. During the 2015-16 academic year, 16.1% of the undergraduates received financial aid and 57% of financial need for those students was fully met. The average need-based financial award was $12,900, and the average loan was $4,500. Although 67.6% of students at Armstrong qualified for aid, only 23.8% who qualified for aid received any. Thus, many students worked and 87% held loans despite the low cost of tuition. The university has 265 full-time and 179 part-time faculty, and a student/faculty ratio of 17.5:1. Many of the Armstrong faculty worked with students during the academic year, but there was no established summer research program until the beginning of this project.

HAMILTON MODEL OF EARLY INTRODUCTION TO RESEARCH

The model of intervention of early introduction to research was pioneered at Hamilton College thanks to several grants from the Camille & Henry Dreyfus Foundation and a $100,000 grant from the National Science Foundation’s Science Talent Expansion Program (NSF-STEP). A pilot study, funded initially by a Dreyfus grant, involving 15 students who worked in chemistry laboratories the summers of 2000, 2001, and 2002, formed the basis for this model. Details of the Hamilton model can be found in this previous publication, but we will provide a brief summary here. The main idea was to immerse incoming college students in a summer research program between graduating from high school and beginning their first year of college, with the goal of increasing the number of students who major in STEM disciplines. The program ran for seven summers, from 2000 to 2006, and detailed statistical outcomes were published in 2010. The summer bridge program involved intensive research in an active research laboratory of one of the faculty and a learning community to address social needs. Approximately 11 students were recruited each year in concert with the admissions process from 2003-2006, 44 in total, who were combined with the original 15 for purposes of evaluation. Students were selected from all ability ranges in the applicant pool, thus allowing for a significant number of students who were at the lower end of the Hamilton applicant pool. The grants paid a stipend of $350 per week for five weeks of research for each student participant. Hamilton provided a second summer of research for 10 weeks for all STEP students who maintained their intention to major in a STEM discipline in one of the next several summers. Faculty were not compensated for mentoring a research student, but did use the opportunity to train students to be productive scientific researchers by the end of their second summer. Many Hamilton faculty had research funding from the NSF and NIH that paid summer salary, and all Hamilton faculty who worked with two or more students during the summer received a stipend of $1000. While faculty from all STEM departments participated, the chemistry faculty served the most students. Faculty with active research grants often kept STEP students on for additional summers, thus increasing student understanding of the scientific method and increasing the productivity of the faculty member’s laboratory. The students were housed together in a special housing unit, with two upper class
science majors as resident advisors, which fostered a strong sense of community among the participants. Room and board was partially subsidized, with the costs to the participants being $35-$50 per week over the duration of the STEP program.

A total of 59 students were immersed in early introduction to research from the summer of 2000 to the summer of 2006, spanning the four year expected graduation years of 2004-2010. A detailed statistical analysis using a control group of applicants who were not accepted, controlling for admissions applicant rating and SAT scores, allowed for robust findings from the Hamilton study. Graduation of the control group was 89% while graduation of the students in the STEP program was 97%. While 59% of the control group majored in a STEM discipline, 75% of the STEP students majored in STEM. In addition, STEP participants had an increase of 0.25 GPA points on a 4.0 point scale, when controlling for admissions rating, SAT scores, race, and gender.4

Increases in retention, GPA, and STEM major selection were all positive outcomes of the early introduction to research model. To better understand student motivations, we administered surveys each summer and these provided a qualitative understanding of the quantitative results. The STEP students’ main goals as they entered the summer program were to meet their future professors, learn the campus and make friends, gain lab experience to further their scientific interests, earn money and have fun. At the end of the summer, students reported that the main benefits of the experience were equally academic and social. The ability to make good friends and begin advising and mentoring relationships with a few faculty were key social factors, and because the interaction with fellow students and faculty revolved around an intensive scholarly activity of interest to both students and faculty, this program allowed students to integrate important aspects of the liberal arts and sciences college experience. The highly personal nature of undergraduate research at primarily undergraduate institutions is what turns students on to science6 and the combination of social and academic bonding is an example of the decisive role that personal relationships play in determining a student’s success in college.7

WILL IT WORK AT A COMPREHENSIVE REGIONAL UNIVERSITY?

One of the most startling contrasts between students entering Hamilton from those entering Armstrong is the preparation that students have received in high school. While Hamilton’s students are extremely well prepared, with only 5.6% of the Fall 2015 cohort scoring below 600 on the Math SAT, at Armstrong only 6.7% of the Fall 2015 entering class scored above 600 on the Math SAT. We knew that math preparation was a likely cause of the inability to succeed in STEM fields at Armstrong and other regional public universities. The six-year graduation rate for Armstrong’s CST students was less than 10% at the time we wrote the STEP grant in the Fall of 2008.

A second contrast is in the very unequal actual cost of education for students. In terms of finances, 100% of financial aid was fully met at Hamilton, while only 23.8% of Armstrong’s students who qualified for financial aid received any, and only 57% of those students’ needs were met. Consequently, 87% of Armstrong students took out loans to pay for college.

We believed that the close personal relationships provided by early introduction to research,
combined with enhanced mathematics preparation and financial support, would increase the persistence of STEM students at Armstrong. Therefore, we rolled out the Armstrong STEP program in conjunction with the first ever, comprehensive summer undergraduate research program in the university’s history.\textsuperscript{8,9} In addition, because of the high female and minority populations at Armstrong along with the pressing need to increase the number of STEM majors in these populations, we put a special emphasis on these historically underrepresented groups in STEM fields.

In addition to student contrasts, the conditions of faculty life at the two institutions were quite different. Armstrong faculty have a 4-4 teaching load and full Professors earned an average nine month salary of $72,621 in 2014, according to data on the Chronicle of Higher Education’s website. Associate and Assistant Professors earned an average of $55,548 and $47,853, respectively. In addition to low salaries, the University System of Georgia’s policy is to pay nine-month faculty salary over ten months instead of twelve, creating a two-month pay gap that leads faculty to seek additional income, such as teaching summer courses. In contrast, faculty at Hamilton teach a 3-2 load and Assistant Professors start at a higher salary than the average full professor at Armstrong! Hamilton full Professors made an average of $132,228 in 2014, and the corresponding salaries for Associate and Assistant professors were $97,857 and $77,193. Hamilton faculty are paid their nine month salary over 12 equal segments.

**APPLICATION AND EXTENSION OF THE MODEL TO ARMSTRONG**

The typical Armstrong student is first-generation, female and Pell-eligible. Because the university has a mission to serve the local community, a significant number of students are adult learners, active military personnel, and veterans. In 2009, Armstrong State University (then Armstrong Atlantic State University) was awarded a $1.0M National Science Foundation STEP grant to increase STEM retention and graduation, especially for female and minority students.\textsuperscript{8} At the time of the award, Armstrong had a small but growing undergraduate research program, where most students completed undergraduate research for credit during the school year, with a few faculty accepting summer research students pro bono on the part of the faculty member. Occasionally, a handful of faculty had grant support (internal or external) to provide stipends to students or to themselves; however, this was not the norm. In addition, Human Resources limited student work in the summer to less than 20 hours a week, in the mistaken belief that the university would avoid paying retirement and health benefits to summer student researchers. This situation was rectified and, despite the onset of the Great Recession, funds were found to institute the first comprehensive summer research program in Armstrong’s history in the summer of 2009.\textsuperscript{9} Specifically, the dean used indirect costs from faculty grants in the CST to fund faculty stipends in the summer. Faculty in the program received approximately $9000 to work 10 weeks with summer students, but this amount dropped off after the second summer. Faculty support was dependent upon two conditions. First, faculty were required to focus their efforts on research instead of summer teaching (two summer school courses for Assistant Professors yielded about $9,000 of income). Second, faculty agreed to submit a grant to a Federal agency that would support their future summer research endeavors, at the same time contributing indirect costs back to the college which could be used to support future summer CST faculty stipends. Prior to the first summer of full-time research in 2009, the dean held a workshop to educate faculty on how to obtain the most results and have the best possible positive impact on their research students.
Additional professional development opportunities for faculty to improve their research and success rates with grant requests have been held every year since 2009. In the third summer, faculty stipends were approximately $4500, with similar stipulations that focus faculty on research and grant submissions.

The STEP program consisted of cohorts of 15-25 incoming first year students each year for six years who began performing six weeks of paid summer undergraduate research alongside faculty and undergraduate peer-mentors. The STEP students were paid a stipend of $300 per week and provided with housing during the summer. In addition to research, the STEP students were required to attend a mathematics summer bridge program to help improve their mathematics readiness for STEM achievement, and attend weekly learning community meetings to learn about safety, responsible conduct in research and the research of other faculty and students. Students also received extra advising and counseling from the STEP Director while in the program through a required meeting with the Director at mid-term. Any student in jeopardy of not making the required 2.5 GPA to stay in the program, or who failed to meet the 2.5 GPA in a given semester, was also required to meet with the Director again at the end of the semester. Students who successfully completed their freshmen year (above a 2.5 GPA) and continued to progress toward a STEM degree were offered a second summer of research (for 10 weeks) and served as additional peer-mentors to the next incoming cohort of STEP students. Every STEP student was encouraged to present at a discipline-specific conference and funding was provided to support travel costs. The program was assessed by an outside evaluator, paid from the NSF grant, who surveyed students each year and conducted on-site visits each summer to interview and observe students, faculty, and the STEP learning community.

STEP EVALUATION AT ARMSTRONG

STEP evaluation followed a mixed-model with a quantitative-qualitative design. Evaluation methods included observation, interviews, focus groups, surveys, and document analysis.

Six years of data from both students and faculty confirm the intrinsic value of the STEP program. Consistently through the years, STEP has served as a bridge to college life and to STEM coursework in particular. In interviews, focus groups and surveys, when asked what they have received from participation in the STEP program, students have cited the following: subject-matter knowledge; hands-on experience; laboratory and research skills; preparation for college life; preparation for freshman year of college; preparation for STEM classes; help in selecting or confirming choice of a major; one-on-one contact with their faculty advisor in the research setting; preparation for career or graduate school; and advantages in applying for graduate school or work. This is consistent with research on comprehensive studies on what students gain from undergraduate research. Over 60% of students indicated that the math preparation course helped them with their first semester of math and over 90% indicated that the STEP research project helped them with their science classes. Students cited practical or hands-on experience with techniques and instrumentation used in the major field as a major contributor to their success. “STEP showed me the quality of work that was expected at the college level. It showed me aspects of science and math that I did not learn about in high school.”
The peer-mentors and second year returning STEP students often indicated that they had developed laboratory leadership skills and confidence, in addition to increasing research skills, understanding scientific process, and developing research acumen. One student commented “I meet with my students in the morning and outline my goals and expectations for them for the day. Then, they largely work on their own, but I check in on them often…. They are very self-sufficient.”

The 17 veteran STEP professors who served the program for multiple years answered similarly when asked what they gained from their involvement in STEP. Several of these cited the positive effect the students had on the professor’s own research program. “The best research experiences I’ve had with undergraduates have been my STEP students. Having them work all summer and immerse themselves in the project is beneficial for both myself and them,” and “3 great research students have stayed with my work for extended periods of time, which has helped move my agenda forward.” A number of faculty affirmed the importance of undergraduate research and praised the opportunity to mentor students, while themselves becoming a better undergraduate advisor or teacher (e.g. “I’ve applied the teaching skills I acquired in STEP to my regular classes”).

Overall, the professors’ descriptions were uniform in their portrayal of busy, well-organized undergraduate laboratories conducting research in a collegial, supportive atmosphere. Many had initial concerns that taking a pre-first year student into their lab would be difficult due to the student’s lack of background knowledge, skills and techniques. When asked if the students came prepared academically, about 25% of professors gave their students glowing reports (In the lab she is absolutely excellent, all of her stuff is working, technically she is fantastic; she is clearly at a higher academic level, taken AP classes, graduated HS early, lot of different academic experiences); however, most indicated that they couldn’t yet assess or that although the student did not know techniques and/or content coming into the program, they quickly “got up to speed.” (“As expected [student] was severely delinquent in her knowledge of chemistry, however, she picked up on the techniques and concepts quickly… [Student] really is a natural”). In general, all faculty said their STEP students developed self-confidence, increased awareness of their abilities as a researcher, matured, gained communication, presentation and basic laboratory skills, became more versed in their field and made a contribution to the research project.

There is evidence that a genuine culture shift toward undergraduate research has taken place within the College. The years since STEP began have seen a tremendous increase in the number of students conducting undergraduate research. Said one faculty member, “It has encouraged more faculty to devote their summer time to scholarship with students rather than teaching and has contributed to a paradigm shift within the college where more faculty are developing significant research programs that involve undergraduates. It has enabled me personally to gain significant grounds with my research and take on more students than I would be able to otherwise. I am very grateful to be a part of the program…” Finally, a comment from one STEP faculty advisor summed up the role of STEP in producing this “next generation of scientists”: “(The) STEP program proved my point that research culture must be introduced in early years of undergraduate programs in science and technology disciplines for (a) having more enthusiastic
students resulting in a higher retention rate, and (b) awakening or increasing the level of curiosity in students of the STEM disciplines.”

OUTCOMES TO DATE

Retaining minority students in higher education is a serious challenge. Data on the Armstrong STEP program, provided by the Office of Institutional Research, the University System, and reported through IPEDS, tracks STEP students against all Armstrong students and all CST majors. Since 2009, when the STEP program began, the College has enrolled 72% more STEM majors overall, with the largest increases being in Chemistry/Biochemistry (175%), Physics (214%), Engineering (99%) and Biology (101%), during a time when numbers of non-STEM majors have remained flat. The number of STEM bachelor’s degrees granted by Armstrong also increased by 43% since 2010. The STEP program directly served 128 students in 9 majors, 86 of whom were pre-first year students while the remaining 42 served as peer-mentors (second through fourth year students). Another 108 students attended various learning community events as additional members of a participating STEP faculty member’s research program. Of the 86 pre-first year STEP students, 48% were female and 36% were minorities, both percentages are reflective of the College’s demographics. Most students were Biology majors (39%); however, there were significant numbers of Chemistry/Biochemistry (28%), Engineering (17%), and Computer Sciences majors (8%). The majors of Physics, Math, and Psychology had fewer participants (2-4%). The first-time, full time, first-year (FTFTF) retention of STEP students to the university was significantly higher than the retention of non-STEP students. Overall, 84% of FTFTF STEP students were retained to the university and 79% of all these STEP students (including minorities, with females at 82%) were retained to STEM majors. In contrast, Armstrong retained 70% of its FTFTF STEM majors to the university, while only 57% of these were retained to the College in STEM programs. Second and third year retention of STEP students into STEM programs remained higher by an average of 7% with the largest effect being on female students (10% higher). Second year retention of STEP minorities was 8% higher than the retention of all second year CST students to STEM majors. Unfortunately, this increased retention dropped off in the third year, as the retention of STEP students to STEM majors was equal to the retention of all CST students to the college. This phenomenon may be a reflection of the national trend referred to as the “sophomore slump”. Of STEP students who were not retained, most were due to a low GPA, indicating that the initial effect of immersing the students into the STEM field through research wanes as courses become more challenging and the services of the STEP program end. Some students transferred to other schools in the University System, since the transfer process in Georgia is rather seamless. In fact, engineering students had to transfer to other institutions to complete their studies. The six-year STEM graduation rate for the first two STEP cohorts (2009 and 2010) was 17.4%, which was higher than the average university STEM graduation rate of 12.4%, but lower than the University’s overall FTFTF graduation rate of 32%. The effect of the STEP program becomes even more pronounced when examining four-year graduation rates. The average four-year STEM major graduation rate for four cohorts of STEP students (2009-2012) is now 21% versus 6.1% for freshmen declared STEM majors overall. This is in comparison to Armstrong’s four-year graduation rate of 13.2% for all majors. Increases in the four-year STEM major graduation rate may be the direct result of STEP students developing a stronger association with a STEM field early in their college career.
promoting a timelier and more direct matriculation. We expect this trend to continue, such that the four- and six-year graduation rates for the remaining cohorts will be markedly higher.

In addition, Armstrong does not have a four-year engineering program. Students must transfer to one of five schools to complete an engineering degree in the state (Public: Georgia Institute of Technology, University of Georgia, Kennesaw State, or Georgia Southern University; Private: Mercer University). Of the 22 Engineering students participating in STEP, 15, or 68%, completed their transfer to a four-year program. Of those 15 students, 11 have graduated with Bachelor’s degrees in engineering fields. When those graduates are added to Armstrong’s first two cohort’s 6-year STEM graduation rates, the rate increases from 17.4% to 37.1% and the 4-year STEP student STEM graduation rate increases to 41.4%.

Over the six years of the Armstrong STEP program, the College of Science and Technology was able to initiate a sustainable undergraduate research and mentoring program that served to increase student success in STEM, especially that of female and minority students. Long-term culture change is evidenced through the increase in undergraduate research participation in the college. This participation has increased 182% since the inception of the STEP program, from 72 participants to 203 participants each year. Student presentations of research increased 257% from 33 to 118, and students were co-authors on 41 publications in the 2015 academic year.

Based on the success of the STEP program, the University hired a College Undergraduate Research Coordinator and committed funds to sustain the summer research programs; however, the current program is run on a smaller scale for both faculty and students and serves only current students and not incoming, first year students. To compensate for reduced opportunities for incoming freshmen, the most research-active departments have turned to incorporating undergraduate research projects and experiential activities into first year courses, such as Introductory Biology and General Chemistry. These changes to foundational courses have initiated a trickle-up effect within departmental curricula leading to development of other course-based undergraduate research experiences (CUREs) and significant changes in the way in which faculty approach the teaching of science in the classroom and laboratory. The overall impact on the research culture at Armstrong has been quite positive, with many faculty now submitting and receiving external grant proposals. This has helped to increase publication rates and has provided additional funding for student research projects.

ADDITIONAL CHALLENGES OF IMPLEMENTATIONS

Over the life of Armstrong’s STEP program, faculty recruitment was often difficult. Both with and without stipend support, some resistance included preference for teaching a full summer course load for more money, faculty who had no need for supplemental income due to a higher base income, a lack of interest in working with inexperienced students, and lack of a research program (or interest in developing a program) that could be tailored to include an inexperienced student. In addition, the STEP program pushed the boundaries of the status quo with student services on campus. Areas such as the library, the recreation center and housing had not previously provided services to students prior to their first semester of registration. This required significant planning and networking with our colleagues to develop new campus models for supporting students in specialty summer programs, including a new bridge program for
underprepared students that began shortly after STEP. As a university that has, only in the last 15 years, begun to build a reputation for undergraduate research, recruiting students to an undergraduate research program in STEM was not always a simple task. Incoming freshmen and their parents required significant education about the value and importance of research for the student’s intended career path. The significance of this opportunity had to be carefully crafted to compete with the desires of new high school graduates to spend more time with friends, family trips and other more profitable summer jobs.

THE NEXT EXPERIMENT – BUCKNELL UNIVERSITY

The success of the early introduction to research model at Hamilton and Armstrong was used as a basis for preparation of a competitive proposal to the NSF, with a goal of creating a program that will increase the number of undergraduate students, particularly underrepresented (i.e., first generation college, students of color, high need, and female) students, who graduate in the sciences by taking advantage of this mentor education model. The program designed for Bucknell, which is academically and demographically more similar to Hamilton than Armstrong, was to prepare these typically underrepresented students for long-term careers in science, either in academia or in industry, through an early introduction to research. In 2013, Bucknell received $450,000 to implement the STEM Scholars program, and has had three cohorts in the summers of 2014 (14 students), 2015 (17), and 2016 (17) to date. Half of these 48 students met at least 2 of 4 diversity indicators (female, student of color, low socioeconomic status, first generation college student). Results so far include an increase in the applicant pool by advertising and offering these research opportunities, and better retention of underrepresented students in STEM because of the development of a cohort and natural support network, by helping students understand the nature of research, and increasing perseverance by normalizing failure and decreasing stereotype threat. Related to that last point, the faculty who worked with diverse students overcame their implicit biases on the ability of these students to be successful in science. Of the 14 incoming students who began in the summer of 2014, 13 remain at Bucknell and all 13 are still in a STEM field. Of the 17 in the second cohort, all 17 are still at Bucknell and 16 are still in a STEM field.

CONCLUSION

The chemistry faculty at Hamilton College pioneered an Early Introduction to Research Model that increased retention and graduation of STEM majors in general, and chemistry majors in particular, as part of a comprehensive program to provide high impact undergraduate research experiences. This model, developed at a small highly selective private college, was adapted to a non-selective regional public university with stunning results. Armstrong State University used institutional and NSF funding to develop its first ever full-time undergraduate summer research program in conjunction with implementation of the STEP program for incoming students. The modal student at Armstrong State university is first-generation, female, and Pell-eligible. Armstrong State University has used this program to increase retention rates, graduation rates, and research productivity in the College of Science and Technology. The STEP program at Armstrong has demonstrated a significant effect on improving graduation rates for students in STEM majors. Overall, undergraduate research participation has increased 182% since the
inception of the STEP program, student presentations of research increased 257%, and students were co-authors on 41 publications in the 2015 academic year. This program has helped stimulate long-term culture change in the college, with more faculty using their summers to pursue scholarship with students, contributing to a paradigm shift whereby more faculty are developing significant research programs involving undergraduates.

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