A Comprehensive Model for Undergraduate Science Education Reform to Better Serve the Underserved

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Failure to succeed in introductory science classes is a barrier to diversification of the scientific workforce. In the early 1990s, it was found that Grinnell College students —particularly those of color, women, and first-generation college students—were entering Grinnell College with an avowed interest in pursuing degrees in the sciences but abandoning their academic goals when they failed to do well in introductory science courses. To address this problem, a program called the Grinnell Science Project was developed to help students overcome three barriers to success in the sciences. We developed this list of barriers from data analysis of performance and issues experienced by students as: (1) unsuccessful acclimation to college life; (2) ineffectiveness of traditional pedagogy; and (3) a lack of mentoring and role models. Results of this project reveal improved grades for domestic students of color, as well as comparable rates of science major completion and pursuit of graduate study for all groups of students. The culture of the Science Division has changed to reflect, both in architecture and in actions, a commitment to establishing a supportive and inclusive community to promote excellent science. The sciences have undergone major curricular reform, including revision of introductory courses throughout the sciences to provide more active and engaged pedagogies and provide increased opportunities for course-embedded and dedicated research experiences.

Introduction

Science is critical to modern society, for the role it plays in the economy, the provision, management and utilization of natural resources, and other benefits of technological innovation, especially those applied to healthcare.[1] Scientific progress depends on having a well-qualified and ample workforce. According to reports from the President's Council of Advisors on Science and Technology and the National Academy of sciences, the US is falling short of this demand. Since white men make up the majority of STEM (science, technology, engineering and mathematics) workers, a recommended approach to make up the shortfall is to make the sciences more inclusive in order to create a STEM workforce that closely matches the demographics of the population.[2,3] Women represent roughly 50% of the general population but only 25% of the overall STEM workforce.[4] As described by leadership of the National Institutes of Health, certain racial and ethnic groups are severely under-represented in biomedical research. For example, scientific research faculty positions are only held by 4% African Americans, 4% Hispanics, 0.2% Native Americans, and 0.1% Hawaiian/Pacific Islanders[5] and little progress has been made to increase their collective proportion, despite increased representation in the US population.[6]

Reform efforts in undergraduate STEM education have been a critical target to improve recruitment and persistence of STEM workers.[7] The fastest growing segments of our population, people of color, are least likely to access quality STEM education and most likely to leave STEM majors.[2] An examination of the number of bachelor's degrees awarded in STEM fields from 1977-2011 reveals that although there has been an overall increase in the proportion of women earning STEM degrees, this increase is largely accounted for by increases in the life sciences such that compared to men, the proportion of women earning degrees in the physical sciences and mathematics has slightly decreased since 2000.[8] Despite decades of attention, the low percentage of under-represented minorities among STEM graduates has persisted).[9,10] A study conducted by the Higher Education Research Institute (UCLA) indicated that the primary cause of this under-representation is very low degree completion rates.[11]

Experiences in lower level science and mathematics courses are an important factor in STEM attrition.[12] We need to target inclusivity efforts here to encourage and support students to ultimately complete STEM majors and pursue graduate study. Numerous national reports[13-15] offer a clear vision of a robust undergraduate STEM learning environment, including evidence that more engaged learning, such as active and inquiry-based learning, and research like experiences embedded in courses, are the kinds of activities that lead to better learning and retention in STEM.[16-18]

In response to data indicating the predominance of the disproportion of white men in the scientific workforce, Valantine and Collins[6] identify the need for scientific approaches to address challenges associated with diversity in science. Among these recommendations, they call for evidence-based approaches to recruitment and training, including effective research experiences and providing mentoring; and interventions that mitigate individual and institutional barriers to effective education and workforce diversity.[19] Handelsman[20] and Packard[21] have published work on developing effective mentoring to assist with this process. The work needed to best understand and evaluate ways to impact attraction and retention in the sciences will likely require examination and comparisons between several successful models across various institutions. Three recent publications, two focused primary on liberal arts institutions[22,23] and another based on experiences at institutions in California, primarily comprehensive institutions from the California State University system,[7] examine and describe processes related to transformational change efforts influencing whole programs or colleges. A number of inclusive models and case studies are available (AAC&U Diversity, Equity, & Inclusive Excellence Resource Hub at https://www.aacu.org/resources/diversity-equity-and-inclusive-excellence, for example), but few include analysis of the long term impact of these programs on student success, measured by outcomes such as proportions of STEM majors, post-graduate activities, and course grades.

Researchers studying the outcomes of programs designed to improve persistence remain interested in the traditional analytic approach to parsing the individual contributions of treatment variables through both field studies and controlled experiments; however, a realistic understanding of the students' experience may require a holistic approach to the program as a complex package of interacting treatments.[24] Here, we describe a comprehensive set of interventions that have been developed and implemented in a coordinated fashion over more than a decade, and we demonstrate their effectiveness at improving rates of success for students from traditionally under-represented groups in the sciences at a small, highly selective liberal arts college. We call these cumulative efforts the Grinnell Science Project (GSP), and we examine the impact of the project by looking at measures associated with persistence in STEM fields. Some of the lessons learned from the GSP have been incorporated into a Web presence and publication, which are outcomes from institutions recognized by the Howard Hughes Medical Institute as "Capstone Awardees"[25] to recognize mature and successful programs making important contributions to undergraduate science education.[22,23]

Institutional Context

Grinnell College is a highly selective, private, liberal arts college with about 1600 full-time undergraduate students. The College has a long history of commitment to equal access and to social justice. Grinnell practices a need-blind admissions process for domestic students and meets their full demonstrated need, resulting in over 90% of students receiving financial aid. Grinnell graduates over 40% of its students with science majors, and ranks seventh on a per-capita basis in producing graduates who pursue doctorates in the sciences.[26] Grinnell asks students to take an unusually high level of responsibility for structuring their education, while providing students with a mentoring relationship with a faculty advisor.

Similar to the development of other programs designed to improve access to the sciences,[7,23,27] our program originated with observations and an examination of data related to student preparation and success. In the late 1980s and early 1990s, a group of Grinnell College science faculty and student life professionals found themselves dissatisfied with the low numbers of domestic students of color graduating from Grinnell with majors in sciences. Data indicated that many such students with a declared interest in science completed majors in the sciences at far lower rates than did other students with science interests. We noted that average grades in introductory science courses were lower for students of color than for other domestic students. In fact, for African American students, the average grades in introductory level science and mathematics courses was a full GPA unit below majority students, and we looked, then, for a correlation between these students' academic preparation and their grades in introductory math and science courses and found almost no correlation between these grades and their high school grades or standardized exam scores. We did find women earned better grades, on average, than did men, but women still did not persist in pursuing majors in the physical and computational sciences at the rate that men did. Further analysis of information from students' applications for admission showed risk factors for poor grades to be: status as a first-generation college student, graduating from a high school where fewer than half the graduates enrolled in college, and being a domestic student of color. *Thus, the factors interfering with academic success in the sciences were more likely to be social and environmental than academic. Our intervention strategy, then, needed to be more focused on social and environmental issues than on academic remediation.* We also committed ourselves to a strategy of mutual adjustment, believing not just that the students needed to adapt to being at Grinnell College, but that we needed to change our approaches to more effectively assist students in excelling.

Objectives of the Grinnell Science Project (GSP)

In addition to the national importance of increasing the size and diversity of the scientific workforce,[2,3] providing an environment in which sub-populations of students can achieve their educational goals is critical. Success in two elements of the Grinnell College mission—to appreciate and nourish diversity, and to provide an education that prepares our students to be contributing citizens in the world community depended upon improving our performance. We created the GSP to address the barriers that we found that inhibited the persistence of some students in STEM at Grinnell College and that, if successful, would more effectively meet the institutional mission. At the highest level, the GSP aims to enable all students' full participation in the Grinnell community, including pursuit of science majors and careers. We targeted our efforts at students who come to Grinnell planning to pursue science and mathematics but who are among the traditionally under-represented populations in science and mathematics, or who are identified by our data analysis as being in a group "at risk." Since we had a long tradition of success in graduating students in STEM, just not as diverse a group as desired, we felt well poised to take on this project to spread that excellence to a group that better represented our student body and the national needs.

Based upon our data analysis and the work of Treisman,[28] we identified three barriers to the pursuit of a science or mathematics major and to full participation in the community. These are: acclimation to college life, ineffectiveness of traditional pedagogy, and lack of role models and contexts for the study of science. The GSP includes program objectives designed to respond to each barrier:

- To foster acclimation to college life through providing a pre-orientation;
- To improve curricula and pedagogy through creating interactive science/mathematics courses and increased opportunities for mentored research;
- To provide role models and contexts for the study of science through mentoring and community building.

These elements are consistent with Graham's persistence model published subsequently.[16] More recently the community has begun to pay attention to social science work that appears to offer a better understanding of factors leading to the lower rate of persistence in STEM by URM students including, stereotype threat[29,30] growth mindset[31,32] and micro-aggression[33-35] which play a significant role in decreased persistence in STEM, particularly at the undergraduate level.

Meeting the objectives of GSP required comprehensive changes. As described below, program elements were created in response to our local data, other efforts for improved pedagogies and inclusive practices available at the time, and outside speakers and consultants. Although a theoretical model for the totality of the changes was not followed, the approach and activities of GSP align closely with recent recommendations[36] for increased diversity and persistence in STEM based on Lewin's theory of "planned approach to change".[37,38] These recommendations were made by a Joint Working Group on Improving Underrepresented Minorities (URMs) Persistence in Science, Technology, Engineering, and Mathematics (STEM) convened by the National Institutes of General Medical Sciences and the Howard Hughes Medical Institute. At their core, the recommendations support Lewin's point that change requires changes at the large system or group level, as opposed to shifting individual behavior.

According to Lewin, objective standards of achievement are necessary to facilitate a sense of achievement and learning.[37] Revisiting hallmarks of achievement are motivational and allow for a spiral approach where evaluation influences planning, and execution. Revisiting data after execution then can inform planning and execution, and so on. This collection and utilization of relevant data is critical for "unfreezing" the status quo and promoting change. Therefore the first and essential step of the Joint Committee recommendations includes the evaluation of the institution regarding equity and inclusion by collecting and evaluating data tracking degree candidates and earners in STEM disciplines across demographic categories.[36] As was the case for the origin of GSP, such data were essential for publicizing and grappling with the discrepancies in achievement between demographic groups and provided information ("diagnosis" in Lewin's terms) for shaping the programmatic elements to address the inequities ("treatment" in Lewin's terms). The data were critical in the design of the GSP program elements, directed by intervention strategies on social issues. Periodic review of data impacted programmatic elements, such as eventually dropping women in chemistry as a targeted group for inclusion in the pre-orientation since success of that group rose to be on par with all students (described below).

Program Elements to Enhance the Participation of Members of Groups Under-represented in STEM

In order to plan and implement the program, we engaged both faculty and student affairs professionals and relied upon advice from students who were members of our target group. A small group of faculty members, student affairs leaders, and a grant writer in the Dean's Office provided leadership by engaging the broader group of faculty and staff in planning and carrying out efforts and in providing faculty development activities. We invited individuals who had undertaken impressive efforts elsewhere as speakers and consultants, and drafted grant proposals both to provide seed funding and to help focus our objectives and efforts. Key grants (see Grant Support section, 1992-94) provided support for the pre-orientation program, hiring term faculty members so that we could offer smaller experimental sections of introductory courses, and engage students from the target group in research projects. Receipt of the grants not only provided financial support, but also kept us focused upon accomplishing what we set out to do. We also put in place a system of gradually phasing out grant support and phasing in college funds for ongoing expenses, so that financial support for the activities did not end at the end of the grant funding. These strategies are parallel to those subsequently recommended by Henderson and colleagues in 2011.[39]

Component 1: Pre-Orientation

Objective: To Foster Acclimation to College Life.

We designed a one-week pre-orientation, intended to build confidence and to alleviate the anxieties of the first year, since these may create an uncomfortable campus climate for a student and hinder his or her academic performance. This pre-orientation is held the week preceding general orientation for new students. Using the students' college applications and their transcripts, students with risk factors (from our data analysis described above) for poor performance in introductory science courses (none of which involves academic preparation) are identified. The selection of these targeted students is based on their being one or more of the following:

- a first-generation college student;
- a graduate of a high school where fewer than half the graduates enrolled in college;
- a domestic student of color (Hispanic, African American, Native American/Pacific Islander, or Asian American, who were underrepresented in STEM at Grinnell); and/or
- a woman interested in physical and computational sciences.

From that group, students who have indicated an interest in science on their applications and have accepted admission to the College are invited to participate in the pre-orientation. This has resulted in participation of 25-35 students in the early years, and 40-50 in recent years. These selection criteria have changed modestly over time. For instance women in chemistry were originally included, but were then omitted all as the number of graduates reached parity with men, and originally including all Asian Americans, but recently only those who otherwise qualify.

The aims of the pre-orientation include:

- providing a small student cohort in which relationships and a support network may be built;
- creating supporting relationships between students and a variety of science faculty;
- acquainting students with an array of support services the College provides;
- identifying particular academic or writing weaknesses; and
- helping students become comfortable with the campus geography, the library, the computers, and residential life.

According to a national survey of four-year colleges and universities across the U.S. by Barefoot, Griffin, and Koch,[40] most (93%) bridge programs strive to support student development of academic readiness. This element is not part of the GSP pre-orientation due to the focus of our intervention strategy on social issues. However, strong faculty involvement and close and frequent interactions with faculty from across the Science Division is a key feature, one which makes it distinct from our general first-year orientation. These students meet faculty members who teach introductory science and mathematics courses and hear faculty expectations for students in these courses. Students also participate in faculty-led sample classes and a research-like project. Additionally, faculty members participate in many of the social events, starting by dining with the students and the families when they arrive on campus. Six to eight student assistants help with both the academic and the residential-life aspects of the pre-orientation. Since Grinnell asks students to take an unusually high level of responsibility for their college experience, both in the academic and student life realms, developing a comfort with using faculty, staff and more experienced peers as mentors is crucial to success. Developing those relationships is a key goal of the pre-orientation.

The GSP students and their families, many of whom are involved in college education for the first time, have the opportunity to meet other students, learn about the services and structures of the college, and meet faculty. The target population consists of students who express an interest in science and mathematics, indicating that they come with common interests. The smaller size of the group, compared to the general orientation, fosters student-student and faculty-student relationships that help build a supportive mentoring network for the next four years. The burdens of adjusting to the many new demands made on the students are relieved by the personal attention they receive during the pre-orientation. Furthermore, the participants are local “experts” when other new students arrive, and can offer directions and advice to them, further bolstering their confidence. Thus far, over 900 students have participated in the pre-orientation program. Over time, the pre-orientation successes have informed and helped us to improve our general student orientation programs, which are primarily run by our student life offices. Additional information about the pre-orientation program can be found at https://serc.carleton.edu/lsamp/bridging/programs/grinnell.html.

Component 2: Engaged Learning in Science and Mathematics Courses

Objective: To Improve Pedagogy, Especially in Introductory Science and Mathematics.

Engaged pedagogies[41] are a key element for efforts at inclusion in the sciences.[16,42] A leader in mathematics education for under-represented students, Professor Uri Treisman, named three main elements of interactive learning: (1) a focus on helping participants *excel*, rather than merely to avoid failure; (2) an emphasis on collaborative learning and the use of small-group teaching methods; and (3) faculty sponsorship, needed to nourish the program and enable it to survive.[28] Traditional classroom methods have proven to hinder academic success for the target population.[43] When faculty use active learning strategies in the classroom, as opposed to traditional lecture style of content delivery, student failure rates decrease and exam scores increase.[44] Our curricular and pedagogical changes remove the burden of adapting to traditional styles of learning. This work has evolved over the past 25 years, and the changes have proved far more pervasive, as described below, than we originally imagined.

The curricular and pedagogical development component of the program has aimed at changing the basic fabric of introductory courses by providing faculty members with a nurturing environment, mentoring, and the intensive development time they need to make such changes. The President and the Dean of the College supported this work, both intellectually and financially as well as in the faculty reward system, with a special emphasis on supporting the integration of teaching and research.

The goals of our curricular and pedagogical changes are to provide challenging, not remedial, problems which engage the students in hands-on investigation and mutual realization of the solutions, and to respond to different learning styles. We started with several experiments. We launched a series of one-credit (the regular course is four credits), add-on courses that students could co-enroll in with the standard introductory courses. These one-credit courses provided students with interactive ways of learning material, and provided platforms both for more engaged learning by students who wanted some additional work, and for pedagogical experimentation by faculty members. The experimentation by faculty members allowed one or more individuals to try some engaged learning and investigative approaches without having to convince all course instructors or to give up class time in the regular course. In addition, our physicists decided to experiment with a variation of the workshop (no lecture) physics approach pioneered by Priscilla Laws[45] for one of the three sections of the introductory physics sequence, and the entire computer science faculty decided to transform their introductory courses into a workshop format.

After two to three years, faculty members became convinced that learning improved dramatically as a result of these experiments.[46] As a result, the engaged pedagogies were integrated into the standard courses, and the one-credit courses were abolished. In physics, roughly half the students now opt for the workshop format and half for the more standard lecture-lab approach. The first course in computer science is taught entirely in the workshop format, and substantial portions of many other CS courses use active learning approaches. The introductory biology course is entirely based on a research project.[47,48] Some chemistry sections are taught entirely in a workshop format and others use many engaged learning techniques, including research-like projects and learning in the context of a social problem (global warming, water quality, etc.). Psychology and mathematics also use a number of engaged learning approaches. In all, these changes, along with increased levels of student-faculty research, substantially increased faculty mentoring of students at all levels of the curriculum. In addition to new pedagogical approaches, the sequence and content organization of the 100- and 200-level biology and chemistry courses have been revised to ease the scheduling and performance pressures on first year students.

Resulting from a decade of emphasizing curricular reform and active learning in the science classroom, departments across Grinnell's Science Division teach groundbreaking introductory courses. Where many biology departments are struggling to fit more and more material into the introductory course, and only a few have even broached the idea of workshop-style teaching, Grinnell's Biology Department has decided that the most important learning outcome of the introductory course is to get students to think like a biologist. Students in the introductory course read original research papers, design and conduct their own experiments, analyze data, and present results in forms appropriate to the discipline, including posters and research papers. The resulting course aligns very well with recommendations issued in the 2011 report *Vision and Change in Undergraduate Biology Education: A Call to Action*.[49] Where many computer science departments continue to disallow students working together, thereby discouraging students who value teamwork, Grinnell's Computer Science Department embraces collaboration in a wide variety of courses, particularly in the introductory course, which relies almost exclusively on workshop-style exercises throughout the course. By participating in science education that is structured much more like how science is practiced, students are engaged in the practice of science and the relationship with the instructor becomes a mentor-apprentice relationship. New courses and major course revisions are shown in **Table 1**. While there were few research-based introductory science courses in the early days of the GSP, they have become more common and a recent publication provides substantial evidence for their efficacy in improving degree completion in STEM.[50]

Various formal and informal gatherings of science faculty reflect upon our curriculum and pedagogy. Regular meetings of a Science Teaching and Learning Group attract a wide range of faculty, from new faculty to full professors with many years of experience. These provide a venue for mutual mentoring among more experienced faculty members and those new to Grinnell College, among those who have tried innovations and those just getting started, and among newer faculty members emerging from a different pedagogy and those long committed to a didactic style.

Table 1. Major Course Revisions Linked to GSP Objectives

Course	Title	Revisions	Year Implemented
Biology 150	Introduction to Biological Inquiry	NEW, completely inquiry/research-based, workshop format	Fall 2001
Biology 251	Molecules, Cells, and Organisms	NEW, content rearranged, small group work	Fall 2001
Biology 252	Organisms, Evolution, and Ecology	NEW, content rearranged, workshop format	Spring 2002
Biological Chemistry 262	Introduction to Biological Chemistry	NEW, introductory course taught jointly by biology and chemistry faculty	Spring 2001
Chemistry 129	General Chemistry	Content rearranged, hands-on modules, small group work, workshop section	Fall 1997
Chemistry 221-222	Organic Chemistry	Engaged pedagogies, small group work, workshop section	Fall 1999, Fall 2008-Workshop
Computer Science 151-152	Fundamentals of Computer Science	Workshop style, transition to multi-paradigm approach instead of the more traditional imperative paradigm approach	Fall 1992
Mathematics 123-124	Functions and Differential Calculus, Functions and Integral Calculus	NEW, slower paced equivalent to core calculus semester	Fall 1997 / Spring 1998
Physics 131-132	General Physics	workshop sections	Spring 1993, Fall 1994
Psychology 113	Introduction to Psychology	NEW, smaller sections, more experimentally based work	Fall 2002
MAPs 499	Mentored Advanced Projects	NEW, integrate student-faculty research collaborations into curriculum	2002

Component 3: Establishing a community

Objective: To Enhance Mentoring, Collaborative Work, and Students Self-Identification as Scientists

Science and the study of science are facilitated by communities of practice. One of the classic barriers for first-generation college students and students of color is feeling they do not belong in those communities.[51] Building community and a sense of belonging is a key goal of the pre-orientation program, but our attempts to build community are not limited to that. They include much group work in the context of courses, in student-faculty research, and continued support for mentoring relations that give students genuine experiences teaching them to act and feel like they are scientists working within a scientific community. All these and other efforts increase students' confidence, preparedness, achievement, and ownership of the community.

Student-Faculty Research

A critical element of mentoring and feeling like a scientist is student-faculty research. There is a growing body of research documenting how students benefit from research).[52-54] Faculty-student research increases persistence of students,[55,56] and early research experiences seem to be especially effective.[57] We recognized, as have many others, that student-faculty research is one of the best forms of mentoring. We have incorporated small research projects and research-like experiences into many of our courses, including first and second year courses, so that students experience science as it is done and build community with their fellow students as they work together on such projects. We have increased the number of students in our academic year and summer research programs, and regularized the selection process, including a bias in favor of members of the at-risk group. When possible, we have sought to involve members of our target group in research projects early in their undergraduate careers.[56] Based upon our own experience and on what we have learned from our ROLE project led by David Lopatto,[53] we have helped faculty understand ways they can best support student learning in research. We have instituted a formal process of faculty evaluation of students and student evaluation of the program, to assist us in improving effective mentoring. In the late 1990s, in part based upon our successes in the sciences, we established a college-wide program, not limited to the sciences, named Mentored Advanced Projects (MAPs). We also have established department- and division-level activities, such as informal lunches and gatherings with faculty members, focused upon helping students to see themselves as scientists and to help create community. In a typical year, close to 200 student MAP projects are completed in the sciences. Faculty evaluations report that fewer than 10% of these students need close supervision and regular direction, and that over 90% of the students could relate their findings to the context of the scientific work. In a separate project, Jerod Weinman, David Jensen, and David Lopatto found that students' self-reported learning gains from research experiences in computer science improved when these experiences included not only instruction in the important mechanics of research but also grounding in a philosophy of computing science that emphasizes generalized explanation of behavior as a means for control and prediction.[58]

Establishing a New Science Learning Center (SLC) and Math Lab

There is substantial evidence that mentoring is a key component to success and retention of students, particularly those who are members of groups under-represented, in STEM.[21] In 1997 we created the SLC to provide one-on-one tutoring in the introductory science classes and supervision of peer mentors in science courses. (The College already had a long-established Math Lab and a peer mentoring system in biology and chemistry.)[59] It was clear to us that our peer mentoring and tutoring efforts could be improved with some professional leadership. It was also clear that we had something of a gulf between the faculty and students with respect to communication about what was effective and ineffective in our classrooms, and how improvements might be made. Students knew that they were having problems, but they did not have the experience to tell us what to do about it. Hiring a professional director for the SLC, who has both a background in science and in tutoring and mentoring, as well as an awareness of pertinent literature, of interesting projects elsewhere, and of the institutional barriers to reform, has been a tremendous boost to our reform efforts as well as to tutoring and campus climate issues. She has had a strong impact on our project, not only by working effectively with both students and faculty, but also by helping us understand what is needed institutionally to support reform.

The SLC provides one-on-one tutoring for students, training of the peer mentors, and working with faculty, individually and collectively, to improve the learning environment for students. Most first- and second-year courses employ an experienced student peer mentor. Mentors are selected based on their own performance in the course, and on an application that indicates their proposed approach to mentoring, and what they, personally, bring to the goals of the mentoring program. The mentor sits in on all class sessions, assists with active learning experiences, and runs support sessions outside of regular class meetings. The SLC provides pedagogical training for the mentors and a structure for the mentor to provide weekly feedback to the instructor in the course. Faculty have noted that this relationship is really one of co-mentoring, involving the SLC director, instructor, and peer mentor, all aiming to improve student learning. Many of the mentors have been from our target population of students at risk; thus, besides providing additional professional development for the mentors themselves, they can model success to students enrolled in the courses. Mentors report that this experience enhances their learning and aids them in seeing themselves as scientists.[60]

Building Community: Space as a Critical Factor of Creating Communities

The Robert N. Noyce '49 Science Center was completely renovated and expanded in two phases, the first completed in 1997 and the second in 2008. The Center houses all of the science departments—biology, chemistry, computer science, mathematics and statistics, physics, and psychology—as well as the Kistle Science Library and dedicated spaces for the Science Learning Center and Math Lab. Research laboratories have been updated with excellent facilities and equipment. They are also easily linked with classrooms. Based upon our curricular changes, teaching laboratories are designed more like research laboratories, often optimizing cooperative learning. With the increased numbers of workshop-based courses, lab spaces make it easy for students to move between class and lab. Interior glass brings natural light into the classrooms and labs, and increases visibility of teaching and research to those walking by. There are spaces for various sized groups of students to work and study. As reported in Gregg-Jolly et al.,[61] focus groups investigating both challenges and supports for STEM students, they noted (without prompting) that the design of the Noyce Science Center helped to create a supportive community:

> "I think Noyce is extremely excellent for supporting collaboration and openness, because there's just like tables, and you just like walk by, and you see someone at a table, and you chat about the homework. So I think the communal spaces here really do a lot to help that."

> "I can just go to the computer science lounge and see other people and chill with them. Having more spaces where people can have that interaction – that tends to make people feel like they belong."

The Second Year

More recently, we noted that first-generation college students and domestic students of color at Grinnell exhibited a lower level of academic success in second year science courses than other students did. We conducted a mixed method assessment of this work involving both a survey as well as focus groups and interviews of second year students enrolled in second year science courses. We implemented a number of programs to try to improve our success, including a second year retreat for second year science students, faculty development workshops on group or cooperative learning, meta-cognition, and implicit bias. After four years, the success rate of domestic students of color and first generation students improved to nearly that of other students. This work is described in a recent publication.[61]

A Web of Mentoring

Building on Grinnell College's program of close student-faculty interactions in our individually advised curriculum (without core or distribution course requirements), we have created a highly interconnected web of mentoring (**Figure 1**) that supports new students in many directions so that success is not dependent upon a single element. This web also exemplifies our approach of changing the institution to support student success, instead of simply expecting students to adapt to the institution. For example:

- Pre-orientation establishes faculty mentors for new students;
- Pre-orientation provides experienced and accessible student mentors for new students;
- Pre-orientation establishes supportive relationships among new students;
- Follow-up social and informational events with the pre-orientation group further build community and confidence ;
- Interactive classes promote further faculty mentoring for new students
- Cooperative learning strengthens mutual peer support;
- Use of mentors in courses provides experienced student support for new students and helps the new students feel like they belong in the community of scientists at Grinnell College;
- Training of mentors establishes SLC director as support for experienced students and the mentors in co-mentoring relationships with one another;
- Course mentoring establishes co-mentoring relationships between course instructors and course mentors;
- Research projects at multiple levels of the curriculum provide faculty mentoring of research students;
- Science Teaching and Learning Group and other activities promote co-mentoring among faculty.

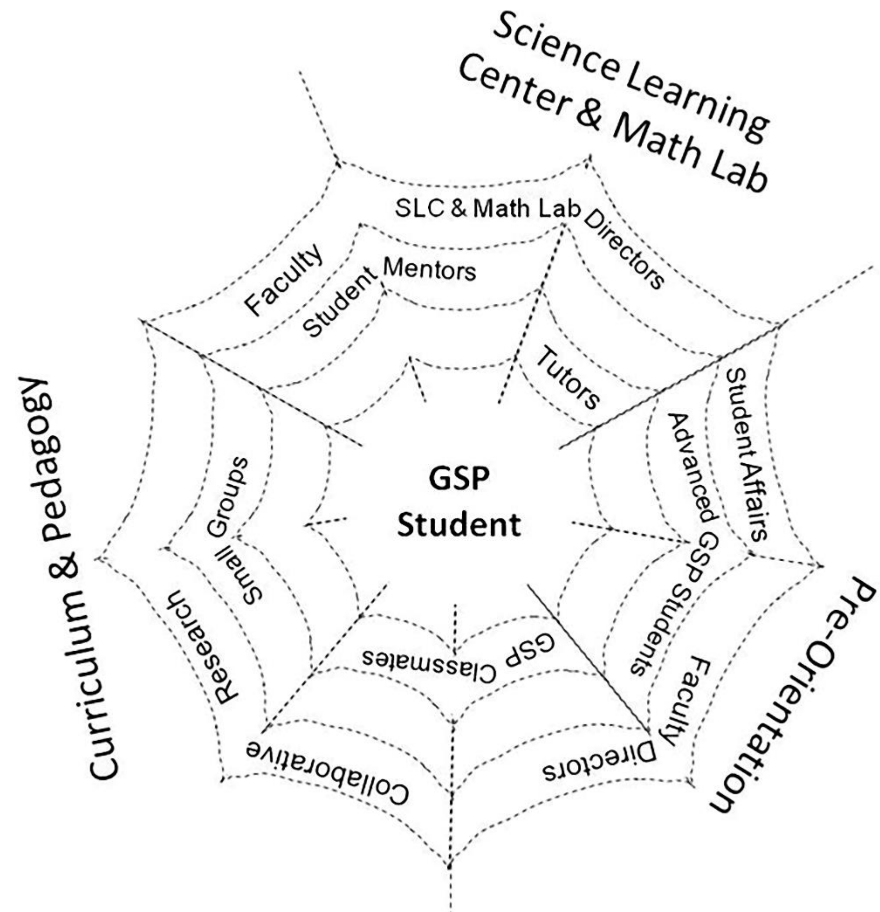

Figure 1. Web of mentoring. Illustration of the comprehensive support network provided for the GSP student. Effective collaboration and coordination between interconnecting elements strengthens the network. Even if a particular element fails, the student is still supported.

Outcomes

Over the past 20 years, the Grinnell Science Project has been remarkably successful on multiple fronts. Over 900 students have participated in the pre-orientation program and thousands have benefitted from the curricular and pedagogical changes as well as mentoring relationships that have been established by the GSP. Another measure of success for the GSP program is that, whereas for women, an interest in chemistry was originally a selection criterion for invitation (due to substantial underrepresentation), the number of women chemistry majors is similar to or exceeds the number of men so that it is no longer necessary to target them specifically. We used official IPEDS race and ethnicity categories as self-reported by our students for our demographic data. There was a change in those official categories during the time of our data reporting, and we have done the best that we can to map them to one another, but the largest impact was creation of a new category of two or more.

Grades

In our first data analysis, we found that African American students' grades in introductory science and mathematics courses lagged behind other students by one full grade point. This was similar to findings by Treisman in calculus courses at the University of California at Berkeley.[28] Other domestic students of color lagged significantly, but by somewhat lesser amounts. During the first few years of the GSP, we found that the grades of students who participated in the pre-orientation program were substantially higher than those who were invited but did not participate. Even though the results were very positive and indicated success, we abandoned this comparison after several years, for two reasons. First, we surmised that there was likely a sample bias between the students who elected not to participate in the pre-orientation and those who did, with those electing non-participation being less committed to the study of science. Second, as the pedagogical and curricular changes became more pervasive, it was not clear that participation in pre-orientation was the main variable accounting for any differences. We now compare the average grades of domestic students students of color (the highest risk factor for poor grades) to those of all students in introductory math and science courses (those that are gateways to STEM majors). We have done this comparison for two multi-year periods in the past decade, and we find that difference in the averages grades of the two groups has shrunk dramatically from roughly 1.0 GPA unit, to about 0.2 GPA units.

Science Graduates

In addition to improving the academic performance of students, so that they could pursue their educational and career aspirations, we hoped that this improved academic performance (grades) along with more exposure to science and to scientists as role models, would encourage them to pursue science majors. The results are impressive.

- Prior to the GSP, from 1992–1994, the College graduated an average of 42 science majors annually who were women and eight who were students of color. By 2015, those numbers had jumped to 77 women (an 82% increase) and 33 students of color (an over 300% increase).
- Three African American women majoring in physics were among the Grinnell College class of 2008.
- Comparing students (who started in 1998–2000) who participated in the pre-orientation to those who were invited but declined, 79% of the GSP participants eventually declared a major in science, while of those who did not participate, only 39% did so. For women, the proportion is 61.5% to 37.9%; for African Americans it is 60.5% to 27.8%. We note that these data may be affected by the selection process for inviting participants and their decisions to participate or not.
- The proportion of physical and computational science majors who are women nearly doubled from percentages in the low 20s in 1990-94 to over 40% currently.
- The percentage of science graduates who are first generation college students increased from 12% in 2004-08 (the first years we have comparable data) to 16% in 2014-16.

The changes in the number of science graduates are shown in **Figures 2-4**. As can be readily seen the number of science majors graduating from Grinnell College has nearly doubled over the past 25 years, but the increase has been nearly all non-white students, with the proportion of white graduates decreasing from 80% to less than 60%.

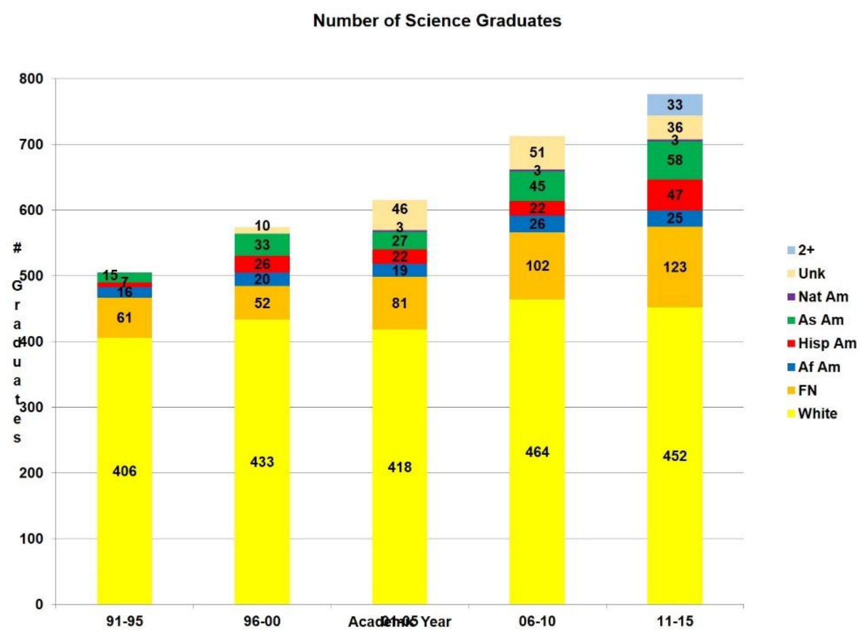

Figure 2. Number of science graduates at Grinnell College for class years 1991-2015. Data for all science majors (biology, biological chemistry, chemistry, computer science, general science, mathematics, physics, and psychology) graduating with a BA degree in the academic year ending in the years indicated. The majors are aggregated by self-reported race and ethnicity: White, Foreign National (FN), African American (Af Am), Hispanic (Hisp Am), Asian American (As Am), Native American (Nat Am), Unknown (Unk), and two or more, 2+.

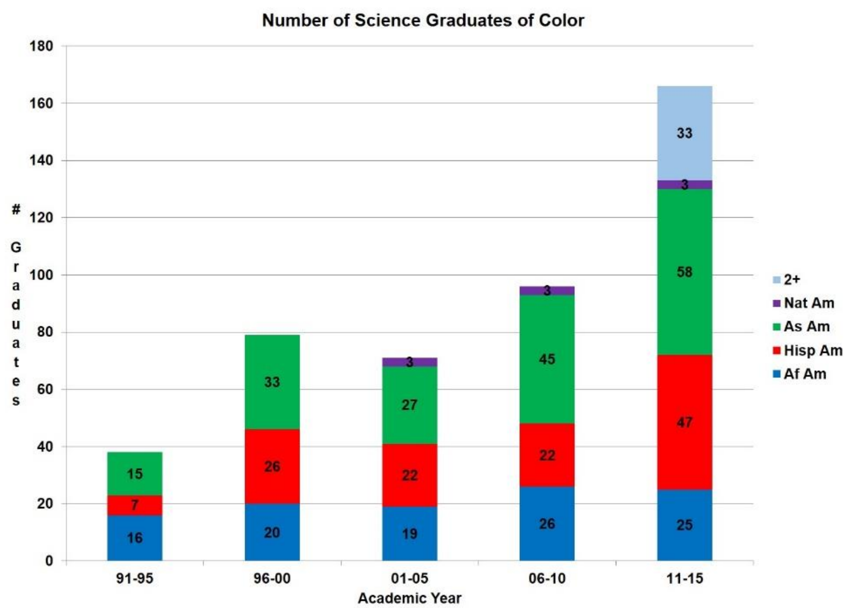

Figure 3. Number of science graduates of color at Grinnell College for class years 1991-2015. Data for science majors (biology, biological chemistry, chemistry, computer science, general science, mathematics, physics, and psychology) graduating with a BA degree in the academic year ending in the years indicated. The majors are aggregated by self-reported race and ethnicity: African American (Af Am), Hispanic (Hisp Am), Asian American (As Am), Native American (Nat Am), and two or more, 2+.

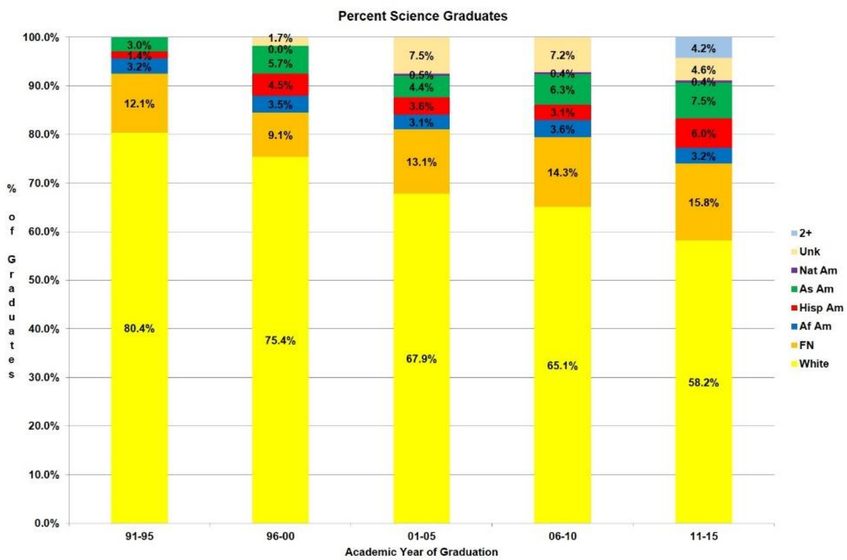

Figure 4. Percentage of ethnic groups making up science graduates at Grinnell College for class years 1991-2015. Data for all science majors (biology, biological chemistry, chemistry, computer science, general science, mathematics, physics, and psychology) graduating with a BA degree in the academic year ending in the years indicated. The majors are aggregated by self-reported race and ethnicity and converted to the percentage of the graduates in that period that fit into each category: White, Foreign National (FN), African American (Af Am), Hispanic (Hisp Am), Asian American (As Am), Native American (Nat Am), Unknown (Unk), and two or more, 2+.

As reported by the National Science Foundation,[26] Grinnell ranks seventh on a per-capita basis among all U.S. higher education institutions in producing science graduates who go on to pursue a Ph.D. Recent graduates who participated in our GSP pre-orientation program were more than twice as likely to pursue graduate study in STEM fields compared to those who did not participate. The GSP is a first step for many of these future scientists.

Curricular and Pedagogical Change

One of the most enduring changes that the GSP has nurtured is a Science Division wide commitment to and faculty development opportunities focused upon curricular and pedagogical reform (**Table 1**). Through building a community of practice that supports engaging and inquiry-based pedagogical approaches, the students experience a curriculum that is focused upon providing excellent learning experiences for them. Student-focused reflection and continuous improvement are the norm, as evidenced by the fact that nearly every faculty member in all six science departments has implemented some change as a part of this community. There are roughly monthly lunch meetings called the Science Teaching and Learning Group. Nearly every summer there is a focused workshop on topics like cooperative learning, metacognition, and stereotype threat.

We believe that this supportive community of practice with a strong commitment to mentoring of students has enhanced our ability to attract and retain a strong group of new faculty as well. In 2017, six out of 54 tenured and tenure-track science faculty members are domestic faculty of color, whereas in the mid-1990s none were.

Becoming a Professional

In a review of the Science Learning Center and the mentoring program, a survey of alumni who were mentors provided some surprising results.[60] More than 75% of the mentors reported the following gains from serving as a mentor: exposure to multiple pedagogies, appreciation for active learning, increased confidence in the subject material and presentation skills, and an increased sense of responsibility and of being a role model. These gains clearly have an impact on the future careers of the mentors: 87% of the respondents were working in science, teaching, practicing medicine, or in graduate training to do so.

In a review of all (over 2400) science major graduates from 2000 through 2014 (see **Table 2**), we found that 54% of graduates had earned or were pursuing a STEM graduate degree. That percentage for domestic students of color was also very high, 50%. Students of color were a bit less likely to be pursuing or to have completed a STEM PhD and a bit more likely to be pursuing or to have completed a health-related graduate degree. We do note that students of color are substantially more likely to be first generation college students, and that might influence their choice of graduate study in STEM or health care.

Table 2. Outcomes of STEM Graduates (2000-2014) from Grinnell College

Student Characteristic	Any STEM Graduate Study	STEM Ph.D.	Health Graduate Program
All STEM graduates	54%	24%	12%
SOC	50%	18%	15%
FN	56%	24%	9%
White	55%	25%	13%
Other	50%	24%	12%
First generation	43%	16%	12%
Non-first generation	55%	24%	13%
GSP participant	51%	22%	12%

The graduates are for all science majors (biology, biological chemistry, chemistry, computer science, general science, mathematics, physics, and psychology) graduating with a BA degree in 2000-2014. The majors are aggregated by self-reported race and ethnicity(White, African American (Af Am), Hispanic (Hisp Am), Asian American (As Am), Native American (Nat Am), Unknown (Unk), and two or more, 2+) Foreign National (FN), or first generation.

Sustainability

The aspects of the GSP that have proven successful have been incorporated into the College's standard operations and budget. The costs represented in the budget for at least the past 15 years include an expanded tenure-track faculty, a full time SLC director, student staff (mentors and pre-orientation student staff), faculty development activities, and the direct costs of the pre-orientation and curricular changes. Certainly, our experience and successes stimulate new ideas, and these are cited in grant proposals to support new curricular and pedagogical projects.

More critical and impressive is that the GSP is simply part of the Grinnell College faculty and administrative culture. Leadership is critical to reform efforts,[7] but that does not mean that the same person or group of people have to continually lead. In the GSP, we found that changes in faculty and student-life leadership have strengthened the program, rather than weakened it. Faculty directors have included members of all of the six science departments. Well over half of the science faculty members, representing all six departments, have participated in some aspect of the pre-orientation program. It is common for a faculty member to serve as a resource person for one or two years, lead one of the research projects the following year, then serve as an assistant director and eventually a director. Thus, we have built-in faculty mentoring and leadership development, with a constant renewal of engaged faculty members. Faculty experience with this program supports a culture of pedagogical reflection to support curricular and pedagogical change.

Grant Support

External grant support (**Table 3**) has done a number of critical things for the project. It forced us to plan and articulate clearly the needs of the project. It provided critical peer review and external validation of our efforts. Finally, it provided seed and developmental funding for GSP activities. These activities are now built into the College's base budget and sustained by internal College funds.

Table 3. External Support for GSP and Related Activities[1]

Year	Organization	Amount	Title	PI
1992	GTE Foundation	$30,000	Minority Undergraduates in SMET	Swartz
1992	The Lilly Endowment	$150,000	The New Science Project[2]	Schneider
1993	GTE Foundation	$30,000	Factor	Swartz
1994	National Science Foundation	$148,683	Multidisciplinary Interactive Introductory Science and Mathematics Reform at Grinnell College	Schneider
1994	National Science Foundation	$49,993	"Learning Chemistry by Doing What Chemists Do"	Swartz (co-PI)
1995	GTE Foundation	$30,000	Focus "Peer Scientists"	Swartz
1995	National Science Foundation	$20,616	A Computational Physics Laboratory and Course	Schneider
1995	National Science Foundation	$2,871,500	ChemLinks: "Making Chemical Connections" (comprehensive reform of chemistry curricula; consortium grant),	Swartz (co-PI).
1996	National Science Foundation	$196,883	Institutional Reform	Duke
1998	National Science Foundation	$500,000	Award Integration of Research and Education	Swartz
1998	National Science Foundation	$75,000	CCLI/Introductory Biology	Robertson
2000	Howard Hughes Medical Institute	$900,000	Undergraduate Science	Voyles
2000	National Science Foundation	$651,885	ROLE/Assessment of Student Research	Lopatto
2004	Howard Hughes Medical Institute	$1,400,000	Undergraduate Science	Lindgren
2003-08	Howard Hughes Medical Institute	$445,029	Assessment of Student Research	Lopatto
2008	Howard Hughes Medical Institute	$1,200,000	Undergraduate Science	Levandoski
2011	National Science Foundation	$10,000	Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring (for the Grinnell Science Project)	Swartz
2012	Howard Hughes Medical Institute	$1,000,000	Undergraduate Science	Gregg-Jolly

[1] Excludes grants with research or equipment acquisition as primary objective.
[2] Now Grinnell Science Project (GSP)

Conclusion

By promoting student inclusion, achievement and excellence in teaching and learning, the Grinnell Science Project addresses the issue of increasing the diversity of the STEM workforce. The project's multifaceted approach uses a range of activities rooted in intensive mentoring and building a community of scientists (students and faculty alike) along with associated curricular reform that supports persistence in science through and after graduation.[16] Over 900 students have participated in the pre-orientation program and thousands of other students have benefited from the curricular and pedagogical changes, as well as from the various activities that we have developed to help build a supportive community. Prior to the GSP, from 1992–1994, the College graduated an average of 42 science majors annually who were women and eight who were students of color. By 2015, those numbers had jumped to 77 women (an 82% increase) and, as shown in **Figure 2**, 33 students of color (an over 300% increase). Since the inception of the GSP, grades for domestic students of color in introductory STEM courses have improved markedly to nearly on a par with other students. GSP alums have established a tradition of high achievement resulting in successful careers as research scientists, mathematics and science educators, physicians, and a few are contributing in other ways, for example, working as patent attorneys or, in one case, as Associate Dean of Admissions & Director of Multicultural Admission. The community of faculty and staff resulting from GSP-related efforts is attentive to practicing what we now call engaged and inclusive pedagogy and is committed to an engaging science and mathematics curriculum rich with collaborative research experiences. We believe that two hallmarks of success of the program were the recognition that 1) we needed to alter what Grinnell College did to take advantage of the distinctive strengths that our students brought to the College and 2) to help build a supportive and engaged community, and that the program is comprehensive dealing with both social and academic aspects of the college experience. The development of mentoring strategies and the curricular pedagogical changes that occurred were stimulated by pioneering changes by faculty members at other institutions (often unpublished), using approaches that are now, more than 20 years later, well documented as effective strategies for improving student learning and retention in STEM.[16,23,36,41,42] All Grinnell science students have benefitted from this community, and this approach to curricular development and mentoring has especially benefitted the groups of under-represented students who participate in the GSP pre-orientation program.

Another critical factor in our success was the repeated use of data. First, data revealed the problem was a social/environmental one, rather than the presumed lack of academic preparation of particular students. Then, data informed a change in our selection criteria for the pre-orientation program as the success rates of our students as well as the demographics of our student body changed. The use of data also helped to bring along faculty members and others who might have initially been pessimistic about whether we had a problem, the nature of the problem, and that changes could result in improved outcomes.

The GSP provides a successful model for engaging students and faculty in a meaningful way and for attracting and training future scientists that is ripe for adoption by other institutions. Perhaps more importantly we provide data regarding long-term impact on persistence that supports the efficacy of those efforts along the lines called for by Valantine and Collins.[6] In 2011, the College received the Presidential Award for Science, Mathematics and Engineering Mentoring. We have worked with representatives of several other national liberal arts colleges,[22,23,62] as well as a regional NSF LSAMP group[63] to collect and disseminate successful strategies to encourage and enable a more diverse array of science students at our colleges.

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Although the two authors of this paper did prepare the manuscript, the work described here represents the efforts of roughly 100 faculty and staff members at Grinnell College over the past 25 years. In particular, Mark Schneider, Professor of Physics, Anita Solow, Professor of Mathematics, and Jo Calhoun, Dean for Academic Advising, were key early leaders of the project. Joyce Stern, Dean for Student Success and Academic Advising, Clark Lindgren, Professor of Biology, Elaine Marzluff, Professor of Chemistry, and Minna Mahlab, Director of the Science Learning Center have been critical leaders over the past 20 years. We are grateful to their commitment as well as for that of our students, who have been articulate in expressing their needs and complimentary on where we succeed and helpful on where we could improve. The College administration was helpful in providing consistent support, both in terms of words of encouragement and appreciation, as well as substantial financial commitments. We thank Susan Ferrari for providing statistics on outcomes of recent STEM graduates, Carlie VanWilligen for assistance with data acquisition, and Erika Jack for essential contributions to preparing this manuscript. Grant funding, as outlined in **Table 3** has also been critical in support of the project.

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