A Compendium of Major Accomplishments and Lessons Learned

2012 HHMI Undergraduate Grants

Howard Hughes Medical Institute
Science Education Department
Undergraduate and Graduate Programs
Science Education Department
Undergraduate and Graduate Programs
4000 Jones Bridge Road
Chevy Chase, MD  20815-6789
www.hhmi.org/developing scientists

Cover illustration: Cytochrome c. Irving Geis.
Rights owned and administered by Howard Hughes Medical Institute.
Reproduction by permission only.
Contents

A Brief History of HHMI and PUIs 4
Overview of the 2012 Grantees 5
The 2012 Capstones 6
Themed Accomplishments for the Non-Capstones 7
  Casting a Wider Net with Course-based Research Experiences (CREs) 7
  Developing Talent and Persistence in Diverse Future Scientists 8
  Competency-based Curriculum Development 8
  Apprentice-based Research Experiences (AREs) 9
  Teaching Science Teachers to Teach Science 10
  A Scientifically Literate and Curious Citizenry 10
The Way Forward 11
Major Accomplishments for Non-Capstones 12
Highlights of the 2012 Mini-grants 70
  Quantitative Biology Mini-grant 70
  CRE Mini-grant 71
  Competency-based Curriculum Development 73
Components of Persistence Programs 75
Lessons Learned 76
Agenda for The 2017 Synthesis Meeting 79
A Brief History of HHMI and PUIs

From 1988 to 2016, Howard Hughes Medical Institute (HHMI) supported undergraduate science education through institutional grants to colleges and universities. Since 1988, a total of 16 competitions were conducted, alternating between primarily undergraduate institutions (PUIs) or college grantees, and research universities. In each competition, approximately 200 institutions were invited to submit proposals.

The college grantees comprised broadly of baccalaureate and master’s granting colleges and universities, of which there are more than 1,300 institutions in the United States (US). Invitations to the competitions were based on the baccalaureate granting institution’s record in producing students who earned science PhDs or matriculated in medical school over the most recent ten-year period.

Over the years, the college grants program had evolved to mirror the larger trends in undergraduate science education. However, HHMI also recognizes that the college grantees, as a result of the selection process applied over the many years, had become a relatively homogeneous group. Because HHMI aims to be more inclusive of all institutions in the US, the 2017 Inclusive Excellence competition was open to more than 1,500 accredited, not-for-profit colleges and universities that offer a four-year degree in the natural sciences. The emphasis of the Inclusive Excellence initiative is to encourage schools to significantly increase their capacity for inclusion of all students, especially those students who come to college via “non-traditional” pathways.

As HHMI transitions to the new model represented by Inclusive Excellence, it is also important to learn from current and past grantees. Thus, HHMI has collected summaries from the 2012 Colleges grantees and assembled them into this compendium.

What happens during the undergraduate years is vital to the development of the student, whether she will be a scientist, a science educator, or a member of society who is scientifically curious and literate. HHMI is investing in these schools because they have shown they are superb incubators of new ideas and models.

Sean Carroll
HHMI Vice President of Science Education
May 2012
Overview of the 2012 Grantees

In 2011, HHMI challenged a cohort of 215 PUIs to develop programs to prepare undergraduates of diverse backgrounds to become leaders in science research, education, medicine, and science literate citizens. Among the 45 awards made in spring 2012, including one for a joint program among the Claremont Colleges, program objectives fell into six primary strategic themes:

- Preparing undergraduates to become K-12 teachers who understand inquiry-based learning.
- Creating curricula that emphasize learning competencies instead of simply checklists of courses.
- Defining and assessing what it means for a student to be scientifically literate.
- Developing effective strategies that promote the persistence of all students in science.
- Creating course-based research experiences that will help students learn science by doing authentic research.
- Encouraging students to engage in research through "one on one" apprentice-based experiences

The strategic theme-based approach is a new opportunity that enables the grantees to organize into smaller groups so that faculty from schools can come together throughout the next four years to share ideas, challenges, (and) solutions.

David Asai
HHMI Senior Director,
Undergraduate and Graduate Programs
May 2012

Visiting Junior Scientist Benjamin Freedman with students Christian Figueroa and Katrina Soto at UPR Mayaguez. Photo by Yolanda Maldonado Ortiz.
The 2012 Capstones

Eleven of the 45 college awards in 2012 were to schools that had been funded in multiple cycles since 1988. These schools were designated Capstones in recognition of their leadership status, and required to show institutional commitment by providing matching funds and contribute to the scholarship of undergraduate science education.

The collaborative scholarship of the Capstones may be found on the website, http://serc.carleton.edu/serc/news/capstone_instit.html, and in a joint publication.1

The Capstones website disseminates lessons learned collectively in four areas, as summarized below:

- **Developing Inquiry Skills**: An inquiry-rich curriculum incorporates elements of research at any stage of student development. An inquiry-rich curriculum structure may be linear or iterative, but a key goal is to expose students to scientific problem-solving processes.

- **Increasing Persistence of All Students in STEM**: The Capstone institutions strive to achieve inclusion through an interlocking network of support, from increasing access to our institutions to supporting students once they arrive.

- **Fostering Integrative or Interdisciplinary Learning**: Training in science, engineering and mathematics content and skills is necessary, but not sufficient to prepare future leaders in STEM fields. Students must also gain experience in applying the knowledge and skills to complex, real world challenges. The role of integrative learning is to increase students’ ability to transfer, apply and synthesize their classroom learning into coherent and usable knowledge.

- **Pathways to Institutional Change**: Despite the overwhelming similarity of approaches to science education, development and implementation is clearly dependent on institutional context.

Themed Accomplishments for the Non-Capstones

Casting a Wider Net with Course-based Research Experiences (CREs)

Research with a faculty mentor is proven to be a key factor in recruitment and persistence of undergraduates in STEM. This success has been so well disseminated that science students, and sometimes their parents, have begun to expect a research experience as part of their education. There is, however, an inherent challenge with major expansion of this apprentice-based model; i.e., the number of students far exceeds that of faculty (or in essence the proverbial demand outstripping supply). This is compounded at PUIs, where faculty have high teaching loads and thus less time for research and are usually less competitive for external research funding than their research university colleagues.

To meet student demand and to expand research opportunities to younger students and students historically underrepresented in science, HHMI invested in the dissemination of a model initiated by HHMI Professor Graham Hatfull, Phage Hunters Advancing Genomic and Evolutionary Science program through its Science Education Alliance or SEA-PHAGES. Based on the success of the SEA-PHAGES as well as results from other CREs, HHMI has promoted the model as a cost-effective way to give diverse students research experiences integrated into their courses.²,³,⁴

Several of the 2012 grantees with CREs as their primary theme are or were members of the Alliance and proposed to expand CREs across more biology courses/sections, or in other disciplines, such as chemistry. The CRE-focused grantees were a diverse group, with CREs adapted to their institutional settings. Several of them participated in the CRE Collaborative Mini-grant and the range of their offerings are evident in a joint publication that resulted from the Collaborative.⁵

The heterogeneity of CREs has led to an effort for a common standard. This was one of the topics of the fall 2016 HHMI Studio, Implementing Course-Based Research Experiences at Scale. Click here for a summary report of the Studio.

See Accomplishments of the non-Capstone grants with a primary theme of CREs: Gettysburg and Tougaloo Colleges and Gonzaga and North Carolina Central Universities.


⁵ Staub N et al. 2016. Course-based science research promotes learning in diverse students at diverse institutions. CUR Quarterly 37: 36-46.
Developing Talent and Persistence in Diverse Future Scientists

Numerous national reports have argued that if the US scientific enterprise is to continue to grow and be creative, it is imperative that our nation recognizes and invests in the development of the talent of students of all backgrounds, including those from races/ethnicities historically underrepresented in science.6,7

College grantees employed a variety of strategies to help diverse students persist in science. They included programs at entry points for multiple undergraduate years, joint research programs between HHMI grantee colleges and colleges that serve different populations of students, such as community or tribal colleges, multi-year, cohort, research-based programs with generous stipends for financially disadvantaged students, academic preparation and college orientation the summer prior to the first year, and customized courses and academic support. All strategies succeeded at retaining students in science beyond the experience or to graduation. However, a major challenge for many grantees was sustaining elements outside the realm of the main curriculum such as summer bridge or first-year research.

Some grantees have begun to look beyond academic factors that negatively affect the performance/persistence of underrepresented students; e.g., psychosocial factors like sense of belonging.


Competency-based Curriculum Development

The 2012 primary grant theme of competency-based curriculum development was inspired by two initiatives that produced seminal reports, both of which redirected the focus of undergraduate science education away from memorization of facts and towards mastery of core concepts and competencies. The first focused on the education of premed students, Scientific Foundations for Future Physicians.8

---


The second, *Vision and Change*, focused more broadly on the education of future life scientists. 9 *Vision and Change* outlined both what needed to be changed and how (e.g., curricular revisions towards student- and evidence-centered teaching).

Strategies among these grantees ranged from developing new competency-based curriculum (e.g., a new global health major) to inquiry-based learning incorporated across a range of science courses—to developing skills in mathematical reasoning or analyzing big data—to revision of organic chemistry, infamously known to be a major obstacle to student retention in science. 10

See Accomplishments of the non-Capstone grants with a primary theme of Competency-Based Curriculum Development: Allegheny, Macalester, Millsaps, and Oberlin Colleges and Southwestern University.

### Apprentice-based Research Experiences (AREs)

The 2012 grantees with the primary theme of AREs sought to expand research into novel areas for students or to expand the opportunities for students, including younger students or those traditionally underrepresented in science, as well as location, i.e., at research-intensive institutions or in the labs of alumni. Strategies ranged from initiation of research-based learning communities, joint research programs with neighboring community colleges, multi-year cohort programs for underrepresented students, and establishment of a genomics program with a focus on societal implications.

Consistent with the literature, these grantees reported a strong relationship between AREs and educational outcomes of students, e.g., graduating in the science major and/or advancing to grad school. Several grantees are sustaining their previously HHMI-funded research opportunities using a variety of concurrent mechanisms such as increased external research funds for faculty, commitments in the institutional budget, and/or alumni or other endowed funds.

Faculty at less research-intensive institutions have come to realize that they often stand to gain as much as their students from undergraduate research, including obtaining preliminary data for grants or working with students whose skills with technology exceed their own. And although lacking in graduate students, these faculty have found that older undergraduates are competent at helping to mentor their younger colleagues in the lab.

See Accomplishments of the non-Capstone grants with a primary theme of AREs: College of Charleston, Juniata and Lafayette Colleges, and Hamline University.

---


Teaching Science Teachers to Teach Science

Colleges are not typically major producers of teachers, but their small institutional sizes lend themselves to interactions of faculty and students across the science and education departments, and their small class sizes lend themselves to faculty models of engaged teaching.

The 2012 grants allowed this cohort of grantees to strengthen the preparation of teachers through strategies, such as joint faculty appointments between science and education, opportunities for science and education majors to engage directly with precollege students and teachers in the classroom, and opportunities for preservice teachers to engage in course-based research experiences.

In addition to the more immediate outcomes, such as the professional development of the participants, these programs achieved long lasting reform such as: permanent changes to the preservice education curriculum; new bridges between science and education departments; a path towards more substantial investment in science teacher preparation; and, by working side by side with science majors, a sense of professional identity for preservice science teachers.

Of all the 2012 grant themes, science teacher preparation proved the most challenging, mostly due to circumstances external to the grant. For example, some schools experienced drops in recruitment mirroring the national decrease in enrollments of students seeking certification in secondary science education.

See Accomplishments of the non-Capstone grants with a primary theme of Science Teacher Preparation: Lewis and Clark, Luther, St. Olaf, and Whittier Colleges, and University of Puerto Rico Cayey.

A Scientifically Literate and Curious Citizenry

Although science literacy has been a theme of HHMI’s undergraduate science education program since its initiation in 1988, most grantees have chosen to focus their grant resources primarily on their science majors.

A strategy to increase science literacy was professional development for a broad swath of undergraduate science faculty to better engage the interest of science and non-science majors in a wide range of introductory science courses. One grantee’s sole focus was on revision of science courses for non-majors, but reported that the effort proved so rewarding for the science faculty involved that it led to unplanned reform in the majors courses. Another has received a multimillion dollar bequest to continue its efforts to help science majors understand the societal responsibilities of being a scientist, including communicating effectively to non-scientists.

See Accomplishments of the non-Capstone grants with a primary theme of Science Literacy: Bard and Ursinus Colleges and San Francisco State University.
The Way Forward

Although there are no plans for future competitions exclusively for colleges, these schools are eligible for HHMI’s 2017 and 2018 Inclusive Excellence competitions for four-year non-profit Carnegie classified institutions that award baccalaureates in the natural sciences.
Major Accomplishments for Non-Capstones

Allegheny College
Bard College
California State University-Fullerton
Carroll College
Claremont Colleges’ Five Cs
College of Charleston
Franklin and Marshall College
Gettysburg College
Gonzaga University
Hamline University
Juniata College
Lafayette College
Lewis and Clark College
Luther College
Macalester College
Millsaps College
North Carolina Central University
Oberlin College
San Francisco State University
Southwestern University
St. Olaf College
Tougaloo College
University of Puerto Rico Cayey
University of Puerto Rico Mayaguez
University of Richmond
University of Texas-Rio Grande Valley
Ursinus College
Washington and Lee University
Whittier College
The main accomplishment of Allegheny College’s HHMI grant was the development of an interdisciplinary Global Health Studies (GHS) program and curriculum that allows students to explore the multiple determinants of health. Students majoring in GHS take a set of core courses, a flexible yet well-defined complementary set of courses specializing in four dimensions of global health, a junior seminar, and they conduct a year-long senior research project. In addition, students must demonstrate proficiency in a foreign language (see Figure 1). We have built a program that provides students with a solid foundation in multiple methods, approaches and perspectives on global health work while fostering diverse interests and varied professional goals. One of our goals was to provide a major that would appeal not only to pre-health students, but also to students interested in the economic, environmental, ethical, political and social dimensions of health. We also developed a minor for students interested in global health who want to continue to focus their studies in another discipline.

The core classes introduce students to a range of methodological and theoretical approaches to global health work and prepare them to design and complete an independent interdisciplinary GHS senior project (Figure 1). Introduction to Global Health (GHS 130) is a gateway class for majors and minors. This first core course introduces students to the types of topics, problems and approaches under the interdisciplinary umbrella of global health studies. Topics and Approaches in Global Health (FSGHS 201) is a sophomore-level introductory methods class for GHS majors. FSGHS 201 helps students develop a familiarity with qualitative and quantitative approaches to research. Students in FSGHS 201 also engage in basic professional development to prepare them for both field experiences and future employment. Epidemiology (GHS 321) is one of two advanced methods classes in the GHS core that explores the history and methodologies of causal associations, covering evidence-based approaches to global health policy and different data types and methods of analysis. Cultures & Health (GHS 350) focuses on qualitative and/or critical methodologies to address global health work, exploring questions of the diversity of human experiences and the centrality of power to global systems.

In addition to the core courses, GHS majors must take at least one course in each of the four key dimensions of Global Health. Sciences and the Environment courses explore scientific processes, interactions between natural ecological systems and the built environment, and their roles in the production of human health. Ethics and Social Responsibility courses explore tensions between individual and collective decision making, bases for assigning values, notions of political and social justice, and their roles in the production of human health. Power and Economics courses explore global political and economic processes that influence resource allocation, risk disparities, markets and their roles in human health. Cultures and Society courses explore communities’ shared structures, practices, beliefs, histories and values and their roles in human health.

The Junior Seminar (GHS 575) builds on skills and approaches from previous course work. Designed to help students move from classroom learning to independent research, the course includes a class project modeling the independent research process and activities to develop students’ proposal for their senior project.

Senior Research Project I and II (GHS 600 - 610) represent a two-semester sequence that serves as the capstone research experience for GHS majors. In the first semester, students identify project design and
methodological approaches and begin data collection. Their proposal is defended with their committee, and oral and written progress reports are submitted. The second semester emphasizes data analysis, interpretation and presentation. Students complete a written thesis, oral defense and public presentation.

One measure of GHS programmatic success is the large number of students who have declared GHS majors and minors to the Registrar (see Figure 2), as well as the number of first- and second-year students who have sought advice on the program, but have not yet declared a major or minor.

For the last two academic years (2014-15 and 2015-16), we have administered an entrance survey to all students enrolled in GHS 130. Results from the first two years indicate less than 25% had any experiences or travel that caused them to reflect on global health issues, and only a fraction of those students had any experiences directly related to global health issues (see Figure 3). Because of this limited exposure, we recently decided to require a field experience for all GHS majors. As part of this requirement, we approved a mandatory 2-credit seminar to help students integrate their experiences into their academic program. GHS students now participate in a range of programs, including semester study-away (n=27), summer international (n=28) and domestic (n=48) internships, EL seminars (n=13), research (n=60), and extended volunteer positions (n=9).

The results of the entrance survey also allow us to track how students find out about the GHS program (major and minor), and whether the GHS program influences their decision to attend Allegheny. Data from the entrance survey show that for the first year administered (2014-15), only 7% of the students indicated the GHS program was a deciding factor in attending Allegheny. During the second year (2015-16), results showed that the GHS program was a deciding factor for 13%. While these findings represent only two years of data, as the GHS program matures and becomes well known, we may see GHS as a significant recruitment tool for Allegheny.
The objective of the grant was to develop a new model of college science literacy to share among the science education community.

- We developed a website with information on the process by which we developed our faculty-driven model and resources to help others pursue their own investigation and create their own definition, pedagogy, and assessment, [http://scienceliteracy.bard.edu/](http://scienceliteracy.bard.edu/).

- A broadly interdisciplinary committee comprising 12 science faculty developed a definition of science literacy, with a particular focus on what students show know about science by the time they graduate from college.

- Over 12 faculty from biology, chemistry, psychology, physics, and mathematics transformed over 12 courses for non-majors to achieve the goals of our literacy definition. Some faculty worked on more than one course.

- We developed an assessment instrument to assess our students’ ability to tackle real-world challenges related to science, piloted the instrument with ~300 students, and developed a rubric for scoring the assessment.

- On our website, we provide annotated links to resources for defining, measuring, and teaching science literacy, as well as for cultivating change.

- In addition to developing the model, the grant has inspired a cultural change at Bard. For example, as a result of their work on the model, faculty were then inspired to redesign the pedagogy for the intro chem and bio sequences and other courses for science majors, and across the College faculty rewrote the eight distribution requirements.
The grant’s objective was to increase the number of under-resourced students graduating as STEM majors, including community college and high school teachers, and becoming leading research scientists or science teachers through a variety of options for research.

We established a successful method for developing and preparing talented but disadvantaged, under-resourced and underrepresented students for entry into PhD programs in biology, biochemistry and chemistry, with about 65% success.

Our two-year Research Scholars Program selected primarily ethnically underrepresented, and educationally and financially disadvantaged juniors or seniors using an application designed to identify and document these disadvantages. Their academic abilities were gauged on the basis of grades in solid science courses, and letters from instructors and research mentors. Only students with some prior research experience were eligible, to ensure they already understood what entering a research career might entail. We avoided taking those more interested in health-professions. Top applicants were also interviewed directly by the selection committee, to further evaluate their maturity and talents.

The program provided significant financial support that allowed the students not to have to work and devote themselves to studying science and doing research. They pledged to spend 15 hours per week on research during the academic year and full time for ten weeks in the summer. They had to apply for and participate in a summer research program at an R1 institution, to experience how it might feel to be a graduate student. They participated in a weekly 1.5-hour seminar for a total of four semesters. This gave them extensive experience in presenting and discussing research—their own, that of the other scholars, and that of visiting scientists, two of whom were invited by individual scholars to spend a day on campus with them, individually and as a group. First- and second-year scholars were paired to review and present the research of the visiting scientists (two per semester). The seminar also addressed issues such as preparing for the GRE, writing a statement of purpose, and how to prepare for on-campus interviews. The group of 7-8 Scholars (3-4 added each year) developed a community, which was also fostered by regular social activities – such as attending concerts, going to museums, and hiking in the mountains. Presentations were peer evaluated (verbally and anonymously). Scholars were assessed by themselves and their mentors after the first semester in the program and at the end, using an assessment tool developed by our MARC program that addresses mastery of laboratory, presentation and critical thinking skills.

During the nine years of this program (which includes the current no-cost extension year), 31 scholars participated, 20 of whom are in or have completed PhDs (about 65%), and three of whom are in or have completed the MD, DDS, or Pharm D. This exceeded our expectations that 50% of scholars would advance to the PhD. Three more are expected to apply for the PhD in fall 2017. Data from a 2011 NAS report indicate that only 9% of URM students persist in STEM from the BS to the PhD. From the beginning, we were very aware of how difficult it is for our disadvantaged students to persist to the point of actually applying to and interviewing for PhD programs. They usually do not have the time, energy, finances and knowledge to go through the required hoops without a great deal of help, which is often not consistently there for them, even if they are in faculty research laboratories already. Families frequently do not understand the effort and time it takes students to concentrate on gaining the background to become a scientist and need students to contribute towards family income. To gauge our success another way, we defined a control group of talented students in 2014 (runners-up for the HHMI program), whom we are following to determine the relative success of our program. There are no data for this comparison group yet, but no matter what the outcome, the existence of the HHMI program on our campus almost doubled the support available for our exceptionally under-resourced students to prepare for entry into PhD programs, the other program being MARC.

The success of our two-year program for the PhD was evidenced by extensive data from quantitative and qualitative assessments and surveys. Our external evaluator stated that “Participants clearly and eloquently acknowledged the importance and value of the HHMI program to their science career trajectories”. They felt “the program could not have done anything more to prepare them for graduate school.” Alumni surveys showed that even those who did not end up going for the PhD felt the experience had been life-changing, and made them (more likely to be a better doctor, for example). Interestingly, assessment of science epistemological beliefs at the end versus start, using a Wilcoxon Signed Rand nonparametric test, indicated that during the two-year program, the scholars significantly increased their view of science as an
idea-generating activity ($t=3.32$, $df=10$, $p<0.05$).

We found a way of interesting and engaging beginning undergraduate students and high school students in science by having them participate in a Weekend Research Experience (WRE).

Over eight years of our grants from HHMI, 24-26 students (divided into smaller groups) worked on a project that was part of the research of one or two of our faculty during each WRE (one each year), doing experiments and gathering data in the two days of the first weekend, then putting the data together and presenting the results the following weekend (total participation thus 136 undergraduates–mainly from local community colleges, and 48 high school students). Assessments showed that the participants “were positive about their experience” (86.5% very high or high impact 2012-2014). They perceived they learned a great deal, could name several techniques learned, and were interested in continuing in STEM (96% impact 2012-2014). Two separate community college faculty, who helped with WREs, were stimulated to obtain funding and carry out short research experiences for their own students over several years. About 30 of the WRE undergraduates applied for our summer research experience (six slots per summer). Twelve were selected, thus participating in both programs.

We established a unique way of providing a summer research experience (SRE) to triads of two high school students and one science teacher working in individual faculty labs for five weeks.

This program was of sufficient length for immersion in research project and while still leaving time for some recuperation of teachers and vacation for students during the summer. Having three people work on the project full time for five weeks made it possible to make some actual contributions to the research project, as reported by the faculty members involved – a win-win situation. A Wilcoxon Ranked Sign analysis of the SURE assessment revealed that the high school student SRE had a very high/high impact on their personal goals. They reported moderate to very large gains in “understanding science,” “how scientists think,” “the research process,” “how scientists work on real problems,” and learning “that scientific assertions require supporting evidence.”

We also ran a successful ten-week SREs for community college and CSUF undergraduates, with individual students in individual faculty laboratories.

SURE and other assessments consistently indicated a high degree of satisfaction with this program (“very satisfied” and “very likely to choose another research experience”). Wilcoxon Ranked Sign analysis of SURE showed moderate to very large student perception of gains in “clarification of their career path,” “ability to read/understand the primary literature,” “science writing and effective oral presentation skills,” as well as large/very large gains in “understanding the research process, analyzing data, interpreting results, understanding how knowledge is constructed, and tolerance for obstacles faced in research.” Most also had a large gain in self-confidence.

The HHMI program had a major impact on the College of Natural Sciences and Mathematics and outreach.

The program as a whole (the two-year, summer and weekend research experiences) had a strong impact on our college. It enhanced the research activity and collaboration of our faculty–especially within the two largest departments (biology, and chemistry/biochemistry), 28 of whom were engaged in the program and its activities. It increased the research productivity of these faculty by providing them good full time students to carry out the work, and some supply money. It also established a new, solid connection between our STEM faculty and four of our local community colleges, many of whose students enter our STEM programs. A strong connection between STEM faculty and two SRE high school science teachers has resulted in visits to our research labs by their students over the past three summers.
The specific objectives and intended impacts of our project were: 1) expanding the number of research opportunities available for undergraduates and especially underrepresented students in Montana, primarily students at five tribal colleges, 2) providing faculty development opportunities for undergraduate institutions in a state underrepresented by funding, 3) producing professional and peer-reviewed communications based on our findings, 4) enhancing the research culture at participating institutions.

We have greatly expanded the number of research opportunities available for undergraduates and especially underrepresented students. Comparing the four summers involving the HHMI award (2013-2016) with data from the four previous summers (2009-2010), the number of science students completing a summer undergraduate research experience (SURE) at Carroll College more than doubled. These increases were matched or exceeded for the tribal colleges that participated in our outreach program with some institutions implementing 10-week SURE experiences for the first time.

- In terms of absolute numbers associated with our vector surveillance program (including resources from HHMI and others), 39 Carroll students initiated a 10-week SURE, 38 completed the program, and all 39 continued to graduate or are still enrolled at Carroll. Correspondingly, 34 tribal-college students initiated a 10-week SURE, 31 completed the program, and 32 completed a degree or are still enrolled at their host institution.

- Of the Carroll students who have graduated, 9 have entered graduate school, 9 are in medical school, 4 others have entered professional programs in allied health fields, and one is working as an engineer. Of the tribal-college students who have graduated, 12 have matriculated into bachelor programs either in science or in allied-health, one has completed a master’s degree in community health, one is completing a pharmacy program and 5 have found employment with health and natural recourse agencies on tribal lands.

- We provided faculty development opportunities for 7 faculty from 5 different institutions each year of our project. Faculty were exposed to the field, laboratory and analytical procedures of a vector surveillance program, enabling them to implement projects at their host institution. Additionally, faculty were invited to collaborate on co-authored scientific outputs described below. For some faculty, the collaborations resulted in their first opportunity to author a peer-reviewed product.

- During the years of the HHMI program (2013-2016), our working group produced four peer-reviewed journal articles with one manuscript pending review and one more in process.\textsuperscript{1,2,3,4} Compared to the decade prior to the HHMI award, the rate of at least one peer-reviewed manuscript per year more than doubles the publication rate of Carroll science faculty. We attribute the increase to the collaboration across institutions especially with colleagues at Montana State University.

- We have established the first publicly-available archive for mosquito vector distribution, abundance and infection rates for the state of Montana. Federal and state health programs, including the Center for Disease Control, are utilizing our database.

\begin{itemize}
\end{itemize}
In addition to manuscripts, participating faculty coauthored eight presentations at regional and national conferences, and over 60 students presented research at local, regional and national conferences.

The HHMI award created collaborations that will persist beyond the grant duration. Carroll is collaborating with Aaniiih Nakoda College on a bison ecology project funded by an NSF-TCUP award. We will be collaborating with colleagues from Montana State University on a Bureau of Land Management award studying the effects of West Nile Virus on sage grouse. We are partnered with Chief Dull Knife College on a Bridge-to-Baccalaureate program funded by an award from the Montana INBRE (with further funding pending an NSF award) wherein Carroll will serve as a short-term “study away” site to help build science skills and provide American Indian students with a “stepping stone” to longer, more distant opportunities. Other collaborations are pending.
Collaborative Research across the 5Cs

- Successful in stimulating new faculty collaborations across institutions in Claremont.
- Ten of 12 groups (a total of 25 faculty) whose projects received funding reported that this was a new collaboration for them.
- Fifty students have participated in these projects.
- Eight projects involved faculty at different institutions.
- Four projects involved faculty in different disciplines at the same institution.
- Most projects lasted over a year.

Outcomes

- External funding was received for continuation of two projects and external funding was sought for one other.
- One publication, 8 conference presentations, 5 manuscripts in preparation.

Incoming First Year Program

Both Pomona College and the Keck Science Department of Claremont McKenna, Pitzer, and Scripps Colleges initiated summer programs for incoming first-year students. Recently (2017), we presented a poster at the annual meeting of the American Society for Cell Biology (“Pre-Freshman Summer Immersion Programs to Increase Minority Retention in STEM Disciplines: Two Different Strategies”) describing the different structures of these programs and the outcomes to date.

a) Pomona, High Achievement Program (HAP):

- Designed as a pilot program to increase retention of underrepresented students in STEM.
- Ten students/year on campus for four weeks.
- Fifty percent of time in math and writing classes.
- Fifty percent of time in research lab.
Outcomes

- HAP students show higher retention in STEM than non-HAP students.
- Stimulated other initiatives addressing needs of underrepresented and underprepared students, e.g., special class sections in introductory biology and chemistry, special mentoring programs in sciences and math.

b) Keck Science, Summer Science Immersion Program (SScIP)

- Aimed to improve retention of students underrepresented in science and from underresourced high schools and provide perspectives on learning that build habits critical to academic success in the sciences.
- 30-40 students/year (~60% underrepresented minorities) on campus for 1 week.
- Intensive lab and workshop activities.

Outcomes

- Formal assessment revealed some promising trends, e.g., completion rates of STEM courses in first year averaged 94%, >64% likely to be science majors, minimal (<0.25 grade point) GPA difference in overall courses and STEM courses, and increased sense of confidence and interest in science reported.
- Formal assessment and contact with SScIP alums during their college careers also strongly suggested a need for continued programing and support during the complete undergraduate experience (e.g., many SScIP alums reported difficulty of courses and ability to manage their time effectively as major concerns, more alums reported feeling homesick or struggling with the transition to college and difficulties accessing support resources to a greater degree at the end of their first year than they had anticipated before entering college).
- Research experience of students in SScIP highlighted in presentations at two national conferences, one talk at a local conference, and one publication.
- Three Keck College Presidents have committed to ongoing funding for SScIP; additionally we have obtained some external funding through Scripps College.

Curricular Development

In 2012/2013, several discussions took place to evaluate common curricular needs in the sciences and share approaches taken by specific colleges and departments. The Dean’s Steering Committee was formed in order to provide more direction and to narrow curricular discussions. The priority chosen for the first year of the award was statistics. Nine faculty were chosen from Pomona and Harvey Mudd Colleges and the Keck Science Department to participate in the Statistics Working Group. The group met twice. Members posted relevant instructional materials for review by the other institutions and the benefits of integrating statistical components in introductory life science classes (rather than in a dedicated statistics class) were discussed at length. Over the course of the next year, it became clear that the large differences (both pedagogical and structural) in the biology curricula on the different campuses precluded the development of shared modules on statistics. However, the Working Group did catalyze efforts to update and refine the statistical approaches taken in each department. For example

- At Harvey Mudd, there is more integration of biostatistics (Bio 154) with the introductory biology lab course (BIOL 54), several changes were made to experiments in BIOL 54 to better address aspects of statistical analysis of experimental design, and students are now required to take both courses concurrently.
- At Keck Science, the two-course introductory sequence (Bio 43 and 44) has shifted an emphasis on running particular statistical tests to an exploration of core statistical concepts. Further, faculty are continuing with a large restructuring of the entire introductory lab curriculum. A second biology faculty retreat focusing solely on this will be held in May 2017. Plans for revision have been informed by a pilot section of BIO 44 offered in spring 2015 that included a formal introduction to statistics and featured an almost semester-long experiment contributed to by all students in the section. Additionally, Keck Science developed six new biology labs that focus on quantitative aspects of biology that were integrated into the Keck Science curriculum and offered annually or biannually.
- At Pomona College, the biology department revised its statistics coverage and handouts in the third course in their three-course introductory sequence, developed a community ecology lab which further expands statistical introduction, and added two
new modules focusing on population dynamics and distribution.

In summer 2016, we ran a three-day 5C workshop for faculty on programming using Python. The workshop was based on the first of three modules that comprise CS 5: Green, the biologically-themed version of the Harvey Mudd introductory computer science course that was developed using HHMI funds. The aim of the workshop was to help faculty develop their own short programs, infuse programming and computational reasoning into their courses, and build the foundations to learn more as needed. In addition to the two faculty who ran the workshop, there were 14 participants.

In the end, although we certainly have tangible, positive outcomes from efforts to collaborate across the curriculum and introduce a more quantitative focus to our curricula, the goal to develop modules that could be directly exported from one campus or department to another was stymied by a number of factors. Largely, these were curricular differences between the colleges, the fact that not all relevant faculty were committed to the changes being proposed, and turnover in faculty and administrators.
Our 2012 grant aimed to broaden access to the sciences by embedding high-impact practices into the student experience at the College of Charleston (CofC), using peer mentoring, freshmen learning communities, early research experiences, service learning, senior capstones, and class-room undergraduate research experiences (CREs).

Freshmen learning communities: A major component of both our 2008 and 2012 grants was the development and expansion of science-themed learning communities (LC). Our chemistry-biology pre-med learning community has been running since fall 2008 and our biology-psychology neuroscience-themed learning community has been running since 2009. There is also a calculus-biology LC where a small cohort of URM students take a unique section of lab based on the HHMI-Phage curriculum. These learning communities will be sustained long beyond the end of the grant and have provided fertile ground for the recruitment of high quality majors and neuroscience minors. Key accomplishments of this initiative include:

- Substantial increase in the number of students taking chemistry as a freshman
- Improved 4-year graduation rate (Table 1)
- Improved STEM retention (Table 1)
- Increased engagement in research (Table 1)
- Long-lasting social relationships among students

<table>
<thead>
<tr>
<th></th>
<th>All Non-LC Bio 111 Freshmen</th>
<th>3 cohorts of Chem-Bio LC Freshmen</th>
</tr>
</thead>
<tbody>
<tr>
<td>% 4-year graduation for students enrolled in Bio111 as freshmen</td>
<td>48%</td>
<td>58%</td>
</tr>
<tr>
<td>% 4-year graduates with degree in STEM</td>
<td>54%</td>
<td>74%</td>
</tr>
<tr>
<td>% students who participated in research</td>
<td>4%</td>
<td>34%</td>
</tr>
</tbody>
</table>

Table 1. Effect of Learning Community Participation on Graduation and STEM Retention

Early research experiences: We have established relationships with local high schools to recruit motivated science students to participate in a peer-mentored summer research experience. The major goals of the program were to improve interest in STEM careers for the high school (HS) students and to improve leadership skills for the CofC undergraduates. The high school students were chosen from several local high schools with a goal of improving interest in STEM careers for underrepresented groups. The students worked in labs under the tutelage of a current CofC student on an independent research project supported by the lab PI. Peer mentors participated in training sessions provided by the College’s Center for Peer Education. High school students participated in an end-of-summer poster session alongside all undergraduate research students from the College. Key results include:

- 38 HS students (~30% URM) and 40 CofC undergraduates participated
- 3 HS student co-authors on publications to date
- 90% of students pursuing a college degree; 84% intend STEM careers
- Surveys of peer mentors and HS students both indicate very positive experiences

In addition, for our freshmen students, we developed a multi-department research rotation to provide a follow-up research experience to interested LC students. This concept will be sustained post-grant, though possibly just within departments and not across departments.

CRE and inquiry-based learning in large freshmen level courses: The second semester lab of general chemistry was converted to a CRE, featuring the drug degradation research of Dr. Wendy Cory who leads this initiative. The course is a structured semester-long research project where students are participants in tracing the degradation products of common pharmaceuticals such as acetaminophen and diphenhydramine. The students are introduced to instrumentation (HPLC), experiment design, scientific writing, and data analysis, all while emphasizing traditional general chemistry skills such as solution making, buffers, TLC and other separations. With over 600 students having now participated, key results include:

- CURE Surveys indicate above national averages in many key areas such as critiquing work of others, working individually, self-confidence, learning lab techniques, and scientific writing.
• 71% of students report they are more interested in research after the experience.
• Students preferred the research curriculum to a traditional lab by a 4 to 1 margin.
• Most common descriptors in comments include “purpose,” “goal,” “meaningful”.

At the same time, the biology department was also reinventing their freshmen curriculum to be inquiry-based. The course content and themes explored are still those that are traditionally covered in introductory biology courses; however the reformed inquiry-based labs were intended to foster a richer understanding of how scientific knowledge is generated and validated, both at the experimental level and at the level of communities of practicing scientists (peer-review and publication/presentation). Early semester “practicing inquiry” labs guide students through some aspects of scientific inquiry, but leave many of the decisions (hypothesis formation, aspects of experimental design and predictions) up to the students working in small teams. This elicits student ownership of the experiment and generates interest in the outcome, while also giving students practice applying biological concepts to the design and interpretation of experiments (Table 2).

• The inquiry teaching approach had significantly greater perceived benefits for doing science; understanding science, communicating science; self-confidence; and learning in a community.
• The inquiry labs fostered greater learning gains in conducting open inquiry, conducting scientific investigations and literacy gains in the nature of scientific knowledge and the process of science.

Results of the independent samples t-test comparing the effect of the teaching approach on mean benefits subscale scores.

<table>
<thead>
<tr>
<th>Post-Learning Benefits Subscales</th>
<th>Pre-Reform (Traditional Lab)</th>
<th>Reformed Lab (Inquiry-based)</th>
<th>Significance (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>Doing Science</td>
<td>178</td>
<td>3.12</td>
<td>0.06</td>
</tr>
<tr>
<td>Understanding Science</td>
<td>179</td>
<td>3.14</td>
<td>0.06</td>
</tr>
<tr>
<td>Communicating Science</td>
<td>178</td>
<td>2.94</td>
<td>0.07</td>
</tr>
<tr>
<td>Clarification of Career</td>
<td>176</td>
<td>3.02</td>
<td>0.08</td>
</tr>
<tr>
<td>Self-confidence</td>
<td>175</td>
<td>3.06</td>
<td>0.08</td>
</tr>
<tr>
<td>Independent Work</td>
<td>180</td>
<td>3.11</td>
<td>0.07</td>
</tr>
<tr>
<td>Learning in a Community</td>
<td>176</td>
<td>3.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Science Teaching Confidence</td>
<td>170</td>
<td>2.84</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table 2. Learning Benefits Subscale Regression Analysis
Developing Undergraduate Students as Leaders in Biomedical Research and Medicine: From Bedside to Bench to Bedside to Community Health

This project used two key strategies to promote persistence of all students in STEM: 1) engage undergraduate students of diverse backgrounds (STEM Posse) early and often in important problems in local community health through a vertically-integrated program of problem-based coursework, research, and outreach focused on genetic disorders in local Plain communities, and 2) foster students’ development of lifelong leadership competencies.

The integration of biomedical research into the undergraduate experience through this project promoted persistence through engagement of students in research-based learning communities as early as their first semester. Faculty-led, peer-mentored learning communities fostered STEM retention through early development of critical thinking and active learning skills, self-discovery (“If my peer mentor can do this complex research, and survive organic chemistry, so can I.”), peer support, and key scientific competencies inside and outside of the classroom. “Leadership” in science and medicine requires an accumulation of skills and experience that, over time, yields the intellectual self-confidence required to move impactful new ideas and strategies forward. To instill leadership skills, project faculty and students mentored F&M STEM students in introductory courses related to the project and continued mentoring students until they emerge from capstone experiences as junior principal investigators. Our F&M Leadership Academy promoted peer mentoring and fostered the development of leadership skills in STEM students. Its highly successful Leadership in Biomedical Research and Medicine seminar series provided opportunities for our students, and sometimes our entire campus community through Franklin & Marshall College’s Common Hour program, to learn directly from proven leaders in science and medicine.

Major Accomplishments

An integrated program of course-based research experiences and research-based learning communities as a means for promoting retention. Exposure to undergraduate research experiences ‘early and often’ is a well-documented means for promoting retention in STEM majors.1,2,3 Even at the highly-selective small liberal arts colleges, in-depth authentic research experiences that engage undergraduates in ‘mind-on-mind’ collaboration with faculty members have traditionally been limited to one or a few students per faculty member per year, limiting the reach of these experiences in the retention of STEM students from diverse backgrounds. Through the efforts of 13 program-associated faculty members, we successfully integrated novel basic research, biomedical research, translational research, and public-health research experiences into a total of 12 undergraduate biology courses from sophomore-level introductory courses (Cell Biology; Neuroscience) to research-intensive upper-level elective courses (Advanced Neurobiology; Neurochemistry; Cancer Biology; Epidemiology; Advanced Genetics and Epigenetics; Immunobiology; Public Health Genomics) and senior capstone courses (Plain People and Modern Medicine; Public Health Outreach; Independent Research). Success was measured by institutional surveys of student perceptions of learning gains for each offering of the course (pre-and post-award), CURE pre-and post-scores and comments for each course, and by exit interviews. Prior to our 2012 grant, only three of the courses above included authentic research experiences investigating novel specific aims.

The 2012 award resulted in an almost ten-fold increase in the number of undergraduate students per year involved in course-based research experiences across the 12 courses involved, from 27 students per year in 2011-12 to an average of 262 per year over the five-year funded period (2012-17). Franklin & Marshall College committed to sustain funding for the course-based research experiences described above


on a three-year renewable basis beginning September 2016. This investment will maintain an eight-times increase in the number of undergraduate students involved in the course-based research experiences described above (to a projected 217 students per year) relative to pre-award levels. [Two courses funded by the 2012 award were discontinued following the end of the award period (Plain People and Modern Medicine; Public Health Outreach) to allow those faculty to focus on other Institutional priorities, including our very successful Quantitative and Science Center (QS&C), led by Professor Elizabeth Rice. The QS&C focuses on retention of STEM students through peer-mentoring, tutoring and peer-led supplemental instruction.] The award also added 14 summer undergraduate research fellowships per year distributed across seven program faculty, representing a two-times annual increase from institutionally-funded pre-award levels for those faculty. Summer undergraduate research fellowships funded by the 2012 grant will not be funded institutionally, although the development of a substantial new endowment to support research experiences for pre-health professions students is providing for a modest increase in the number of summer research fellowships per faculty member conducting biomedical research with pre-health professions students.

A coordinated system of faculty-led, peer-mentored research communities based in each investigator’s laboratory, complemented by an intentional building design that incorporates “student write-up areas” connected to each research laboratory, provided opportunities for larger than typical numbers of students to become involved in research as early as the first semester of the first year. Research communities that paired faculty and upper-level student peer mentors with less experienced students just beginning their research experiences promoted retention not only in the research endeavor, but more importantly in the STEM majors.\(^1\)\(^,\)\(^2\) Exit interviews with our students indicated that research community peer mentors were effective in promoting success of their mentees in difficult courses (e.g., organic chemistry) that tend to “weed” students from STEM majors, in encouraging students to stay on track toward completing challenging STEM majors, in supplementing faculty advising on post-graduate educational and career plans, and in accommodating more than one or a few students per lab per year. Franklin & Marshall College is a nationally-recognized leader in increasing access and persistence for all students. Franklin & Marshall’s Talent Initiative, led by President Daniel Porterfield is a systematic institutional strategy for recruiting students of high talent from all sectors of American society. As a result, the socio-economic diversity of the college has increased. The fall incoming first year cohorts in 2006 through 2008 averaged 7% Pell recipients; for the incoming cohorts of 2014, 2015, and 2016, the college has averaged 19% Pell recipients. In the 2015 graduating class, the percentage of Pell students with a STEM major (28%) was roughly equal to that for all domestic students (29%). For the graduating class of 2016–associated with the fall 2012 entering cohort–48% of Pell recipients, as compared to 32% of all domestic students in the graduating class, completed STEM majors. While the 2016 graduating class’ result is extreme, our current estimate for 2017 is that 33% of Pell recipients will complete a science major as compared to 30% for all domestic students. Successes like these result from integration of our STEM focused efforts in the HHMI-funded program with the Institution’s broader efforts to ensure access for all students and diversify our faculty. Since 2012, the college has significantly expanded its financial aid budget and transitioned to a fully need-based aid program. F&M enhanced admission outreach and has built pipelines through partnerships with leading K-12 school networks and college access programs including KIPP, the Posse Program, College Match, Uncommon Schools, Achievement First, Noble, College Track, and a network of rural and urban public schools served by the Pennsylvania College Advising Corps. As a result, as described above, F&M has nearly tripled the proportion of Pell Grant recipients—students from low-income backgrounds—from an average of 7 percent of incoming students in 2006-2008 to an average of 19 percent over the past three classes; 85 percent of Pell Grant recipients who enrolled in 2010 graduated at F&M, compared to 51 percent nationally. In March 2017, the college was awarded an $800,000 Mellon Foundation grant to further diversify our faculty and continue to promote persistence of all students across all majors.
Gettysburg College proposed integrative learning initiatives, course-based and co-curricular research experiences, and community-building activities to prepare our students to be leaders in science research and medicine. These activities fell under three headings: Research Ready, Research Active, and Research Connected.

**Research Ready Accomplishments:** These initiatives encompassed a series of cross-disciplinary, problem-based, and research-oriented courses offered at multiple points throughout the STEM curriculum. As a consequence of this grant, we have developed and/or permanently adopted the following courses:

1. **Bio 113-114:** A First Year (FY) research-based, two-course sequence in the biology department. This course for 16 selected FY students always attracts more applicants (35-50) than we have openings.

2. **Chem 108-X:** This section of the second semester of introductory chemistry has an interdisciplinary focus integrating biology and chemistry. Chem 108-X has been quite attractive to students with an interest in our biochemistry and molecular biology major (BMB).

3. **Chem/Phy-246:** The Physics of Life – This new course is designed to provide a basic familiarity with the most common techniques used in structural biology and their applications to challenging biochemical, biotechnology and medical problems. The course focuses on current state-of-the-art biophysical methods that are being applied to study structure and function of biological macromolecules and biological systems with a focus on the most informative methods, such as X-ray crystallography, NMR spectroscopy, and single molecule techniques.

4. **Chem/Phy-358 X-Lab:** Salty and Fatty – This combined upper-level chemistry and physics lab is designed to emphasize the use of tools in these disciplines to answer questions in biology. This course concentrates on the role of lipids (fats) and ions (salt) in biology. Utilizing multiple biochemical and biophysical techniques, students perform multiple experiments to ultimately answer a complex biological problem.

5. **Bio/Chem-359 X-lab:** Drugs and Cells – In this combined upper-level biology and chemistry laboratory, students design and synthesize organic compounds and determine the impact of structural modifications on these compounds’ biological activity. The semester is divided into two parts: the synthesis, isolation, and characterization of a derivative of a known, biologically active organic compound and the assessment of its effect on cellular biology *in vitro*.

The last three courses are truly interdisciplinary; they are co-taught by faculty from two different departments and typically enroll students from multiple majors. For example, the last offering of Chem/Phy-246 enrolled BMB, chemistry and physics majors. The X-labs show CURE Survey gains comparable to that of a summer research experience. Finally, endowed funds will allow us to offer Chem/Phy 246 every other year and to offer an X-lab every year. We hope to develop at least one other X-lab to put in our rotation.

**Research Active Accomplishments:** The goal was to strengthen and increase research opportunities for students throughout their undergraduate education.

First, we expanded our summer research program under the auspice of the Cross-disciplinary Science Institute at Gettysburg College (the X-SIG). The X-SIG oversaw the application process for and awarding of summer fellowships to selected students as well as research supplies, and ran a summer program that included weekly brown bag lunches where students presented their research, roundtables on graduate school, the importance of communication, and various social events (e.g., ice cream social). The X-SIG has been adopted as a permanent overseer of our summer program and of various interdisciplinary initiatives. The X-SIG board includes six faculty members: one faculty from biology, chemistry, physics, health sciences and environmental studies as well as including the dean of the natural sciences.

Our summer program grew rapidly: we supported 34 research students in summer 2013 and 53 students in summer 2016. This coming summer, with recently established endowed funds, we will support 61 students. In addition, a summer program that started predominantly with faculty from three departments
(biology, chemistry, and physics) now includes faculty from additional departments (computer science, environmental studies, health sciences, mathematics, and psychology).

We have established a fall poster session, where all summer students supported by our HHMI grant were required to present. We also invited any other student who conducted research during the summer to present a poster if they so choose. We scheduled this poster session during family weekend. This has resulted in strong attendance at this event.

We created a for-credit STEM mentored research course (S/U course worth 0.25 credit) that encouraged students to participate in research early in their academic careers. In its first year, 11 students enrolled in either Bio or Chem 290. This current year, 22 students in the fall and 20 in the spring enrolled in 290 courses across four departments.

**Research Connected Accomplishments:** These programs offered opportunities for a more cohesive STEM community and greater retention and collaboration.

We are continuing our interdisciplinary seminars, with funds to bring two speakers to campus every year. Our Science House has also become an established residential program. In its first four years, Science House attracted 25-35 students. For the 17-18 academic year, 93 students have applied for 40 available beds.
GONZAGA UNIVERSITY
Program Director: Nancy Staub, Professor of Biology

Gonzaga University revised its biology and chemistry programs to be more inclusive and research-based through development and expansion of course-based research experiences (CREs), apprentice-based research opportunities for students including off-campus experiences, a cohort program targeting diverse students and off-campus experiences, and outreach by undergraduates to local schools.

- Established a robust summer and academic year apprentice-model research program (see Figure 1).
- Established CREs throughout the biology curriculum.
- We scaled-up the HHMI SEA-PHAGES program for our introductory biology class (Information Flow in Biological Systems) for >300 undergraduates/year. To highlight the research of these students, we hold a Fall-Family-Phage presentation during Gonzaga’s fall-family weekend.
- Other CREs include physiology and biodiversity, ecology, genetics, molecular biology, conservation biology, and endocrinology.
- Revised the biology core curriculum, based on the Vision and Change report, to include two theme-based courses for freshmen: Information Flow in Biological Systems and Energy Flow in Biological Systems. These courses are taught with active-learning strategies and include several case-studies. The lab for Information Flow in Biological Systems is a scaled-up version of the SEA-PHAGES CRE.
- Established and institutionalized our successful outreach program, Science in Action! This program has grown from a fledging program with 12-20 participating undergraduates, to a program with more than 120 students participating each year (Figure 2). This translates to more than 500 elementary students in over 20 classrooms getting a healthy dose of hands-on, inquiry based science over eight weeks during each semester. A manuscript describing our outreach program and discussing the effect on preservice teachers has been accepted with revision to The American Biology Teacher.

2 Staub NL et al. 2016. Course-based science research promotes learning in diverse students at diverse institutions. CUR Quarterly 37:36-46
Institutionalized several programs to promote inclusive excellence and foster a supportive and diverse community within the sciences. These programs include Biology Pathways (1-credit, one semester course for freshmen), Hughes After Dark (peer mentoring program), and the Gonzaga Science Scholars.

Figure 2. Numbers of undergraduates participating in Science in Action! since 2011 (the program started in 2007). Total volunteers per year are routinely now over 120.
The grant sought to give early research opportunities to Hamline first- and second-year students and those from two local community colleges via apprentice-based summer research and course-based research experiences (CREs).

Summer Research
- Funded 40 Hamline University students (from early in their college career) and 48 community college (CC) students (from Century College or North Hennepin Community College) from the summers of 2013-2016.
  - Represents ~33% increase in research opportunities for Hamline students and fills an almost complete void in opportunities for CC.
- Sponsored a formal research symposium, including poster session, dinner and invited keynote speaker.
  - Included students/faculty from all three institutions.
  - Greatly expanded our usual natural science division poster session.
  - Increased the profile of natural science research with administrators.
- Student surveys from first three summers indicate persistence in STEM interest and research.
  - Sixty-four percent of CC respondents gained at least one additional research experience (61% response rate)
    - Sites of research include Mayo Clinic and various University of Minnesota (UM) campuses.
    - Many commented that their initial HHMI research experience gave them the confidence and skills to compete for the additional research opportunities.
  - Fifty-nine percent of Hamline students sought additional research experiences (57% response rate).
    - Sites of research include Hamline, Cornell, Harvard, UM, and Mayo Clinic.
  - While the numbers are small, the rate of pursuit of a four-year degree almost doubled within the group of community college students that pursued a second research experience.
- Four of 8 students who did not pursue additional research are either currently pursuing or have completed a four-year degree.
- Two in allied health fields (nutrition, nursing) others in biology, material Science.
- Thirteen of 14 students who did pursue additional research, are currently pursuing or have completed a four-year degree.
  - 6 in biology or related fields, 3 in chemistry or biochemistry, 3 in engineering fields, 1 in medical lab science
- Eleven Hamline student survey respondents have graduated and 6 are on track to graduate spring 2017.
  - Hamline alumni group include one at EPA and students in graduate programs including medical school (2), PharmD (1), master’s programs in natural sciences (2), and a PhD program in exercise science (1).
  - Of those on track to graduate spring 2017, one is PhD applicant and two are interested in pursuing graduate degrees (PhD) but are taking a gap year.
    - One soon to be 2017 graduate has been accepted to the MD/PhD program at UM. This student came to Hamline as a pre-med then performed HHMI-funded research at Hamline after her first year, then HHMI EXROP at Harvard the next two summers. These experiences were integral to acceptance to MD/PhD program. As a Somali woman, she will be forging new paths as she continues her education.
    - More than 92% of our students responded to the SURE III survey and 93% reported the experience exceeded expectations.
      - Participants consistently reported higher learning gains (vs. similar programs in other institutions) in Understanding science, Understand research process, Self-confidence.
      - Many of our research students (both from Hamline and CCs) presented their work in a variety of venues (National Conference on Undergraduate Research, Minnesota Academy
of Sciences Symposium, and field-specific scientific meetings). These data suggest that both CC students and Hamline students had very similar benefits from participating in our program. Gaining first research experiences early in their career was clearly beneficial to getting subsequent opportunities. Comparison data for our community colleges is not available as it is very hard to track students at these institutions given their numbers and transiency. While it is early to tell how these data will compare to historical data from Hamline (most participants have not graduated yet), the numbers certainly seem promising and seem to exceed rates of graduate admissions among recent Hamline graduates in the Natural Sciences (self-reported alumni data). Although we cannot prove that these students would not be in the same situations without the HHMI summer research experience, these large numbers of retention and pursuit of higher degrees suggest this early research engagement is beneficial to STEM retention (as has been reported by others).

CREs

- Implemented three CREs over the course of the grant (antibiotic resistance genes (ARG), chemistry, and physiology).
- More than 1,000 students have participated in our first CRE on antibiotic resistance genes (ARG)
  - Most at Century College, but also many at Hamline and North Hennepin
  - Allowed access to authentic research experience to far greater numbers than our research program alone and brought that experience to many students from underrepresented groups.
  - Presented various aspects of ARG CRE at national professional meetings, including ACUBE, ASMCUE, ASCB.
  - Published in open access journal (http://www.coursesresource.org/courses/antibiotic-resistance-genes-detection-in-environmental-samples).
  - Authorship includes Century College and Hamline faculty.
  - Student learning gains from ARG CRE in relevant biology concepts are evident (see Figure 1, difference Pre- vs Post-test are significant by T test, p-value < 0.01).
- Students also expressed an increased comfort with performing research at Century College (survey data).
- Century College is continuing ARG CRE, its first CRE, beyond the grant duration due to strong faculty buy in and leadership.
- Provides concrete access to a research experience for Century biology students across multiple courses within the curriculum.
- HHMI funding and grant related programming has provided Century College biology faculty with a cohort of colleagues that work together to discuss mentoring and pedagogical methods.
- Ongoing commitment to continue to integrate research experiences that are student-centered.
- Developed new institutional infrastructure to support ongoing and new research initiatives.
- The collaborative relationship we have been able to establish between biology faculty at Hamline and Century College has benefitted both faculty and each of our student populations and we intend to sustain and continue to develop our close ties beyond the scope of the grant.

![Figure 1. Learning Gains in Antibiotic Resistance CRE](image)

Percent of correct responses

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamline</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>CC</td>
<td>70%</td>
<td>85%</td>
</tr>
</tbody>
</table>

Legend: Hamline, CC
With this award from HHMI, Juniata College accelerated implementation of a Genomics Leadership Initiative (GLI), an effort to continue transforming our campus into an exemplary site for preparing undergraduates to assume leadership roles in scientific research, medicine, and society. The award has led to increases in the capacity to engage undergraduate students in both scientific research in genomics, as well as research on the ethical, legal and societal implications (ELSI) of genomics research. We used the HHMI award to (1) integrate faculty and student research around cutting-edge technology; and (2) develop a new interdisciplinary curricular program leading to a certification in genomics that addresses the science and the broader ethical, legal, and social implications (ELSI) surrounding progress and discoveries in the field of genomics, while exploring aspects of leadership itself.

As a result of the integrated research program and related curricular changes leading to a certificate in Genomics, Ethics and Society, Juniata achieved the following measureable outputs and outcomes:

- A total of 44 undergraduate summer research stipends and 22 faculty summer research stipends were awarded to support a mentored apprenticeship-based undergraduate research experience over the four program years. This is a 300% increase from prior years.
- A high performance compute cluster was also purchased to support the research program. The cluster has over 200 different users annually, and has already performed over 31,000 jobs.
- A new branch of the intercollegiate genome consortium for active teaching for formed, focused on implementing next generation sequencing technologies in the undergraduate classroom (GCAT-SEEK).
- Over 125 faculty from colleges around the country attended GCAT-SEEK workshops, and 4,000 students used GCAT-SEEK data, manuals or computational resources. Of these, 500 students were engaged in a research setting.
- A total of 15 courses were newly developed or substantially revised to include genomics instruction and themes, leading to the creation of a novel undergraduate certification in Genomics, Ethics and Society.
- A total of 27 students will have completed the new certification in genomics by May 2017.
- An average of 320 students (one-fifth of the student body) are taking at least one genomics-themed certificate class per year, facilitating a more enlightened and scientifically literate citizen-graduate irrespective of major discipline.
- Students demonstrated proficiency in defined learning outcomes assessed with direct and affective assessment instruments.
- Students participating in the certificate and research programs won national awards and have gone on to employment, graduate and medical programs.
- Faculty have committed to continuing a learning community focused on supporting the certificate program.
- A new major in data science and minor in global health have emerged from the HHMI-sponsored faculty learning communities.
- Products of the research program, faculty learning communities, certificate program and inter-collegiate GCAT-SEEK network.

Approximately $2.6M in additional extramural funding from faculty funded from the Juniata summer research program

- A $450K NSF RCN/UBE grant to expand the scale and scope of the GCAT-SEEK network. Three workshops were hosted at Minority Serving Institutions.
- A $300K grant from the Department of Energy’s Community Science Program entitled “Systems Biology Approach to Fracking for Environmental Monitoring”.
- An NSF RCN/UBE grant of $500K to fund a network of educators interested in exploring function of unknown genes in yeast as a framework for undergraduate research based labs.
- A $250K NIH Area grant to support undergraduate research to examine cellular signaling pathways associated with aging associated with aging using C. elegans as a model system.
- A $330K NSF campus infrastructure grant to improve internet connectivity speeds in support of the GCAT-SEEK network.
• $800K in many additional smaller grants supporting undergraduate research.
• Prior to 2012, Juniata College faculty had only $50K in genomics research funding.

Twenty-seven HHMI-supported peer-reviewed articles

• Twelve peer-reviewed, disciplinary articles or books published.
• Three peer-reviewed, educational articles published.
• Eight peer-reviewed, disciplinary articles or books in review.
• Four articles in prep.
• Publications involved ten different faculty authors from five different departments.
• Publications involved 25 different student authors (four students first authored papers).
• Prior to 2012, Juniata College faculty published no disciplinary papers in genomics and only one educational paper.

Juniata has prepared undergraduates to assume leadership roles in scientific research, medicine, and society with (1) depth of understanding in their discipline, (2) the breadth of knowledge and reasoning skills inherent in a liberal arts education, and (3) experience applying these skills and concepts through guided research activity. Understanding the scientific foundation of genomics provides the focus for developing a strong, interdisciplinary base and cross-disciplinary knowledge of the life sciences, thereby serving as an anchor for student learning experiences in the genomics-centered program.

1 http://www.juniata.edu/academics/departments/biology/areas-of-study/genomics-leadership-initiative.php
Our primary theme was Apprentice Based Student Research and four major accomplishments included:

1. A significant number of early mentoring and research experiences were provided.
2. More first generation and underrepresented minority students obtained research experience.
4. We have more computational biology in our curriculum.

1. **A significant number of early mentoring and research experiences were provided.**
   
   Our Science Horizons Program had both mentoring and research components. We were anticipating that meeting with faculty mentors on a regular basis outside of the classroom would provide extra support and guidance to assist students in making the transition to college as science majors and in persistence overall. We were anticipating that participating in an early research experience would motivate students and stimulate their intellectual curiosity. The program was successful in getting students involved in research earlier. Over the past four years, we mentored 78 first-year students in research over the January interim sessions compared to no first-year students participating in interim research during the four years prior to our HHMI grant. We also mentored 29 rising sophomores in summer research during the past four years compared to 8 rising sophomores during the four years prior to our HHMI grant. These students also seemed to persist in research. From cohort 1, we found that 50% of Science Horizons students were engaged in independent research during their senior year with 33% enrolled in Honors Thesis and 25% successfully graduated with Departmental Honors. From cohort 2, we found that 59% of Science Horizons students were engaged in independent research during their senior year with 47% currently enrolled in Honors Thesis.

2. **More first generation and underrepresented minority students obtained research experience.**
   
   We provided more students from underrepresented populations (URP) with research experiences. Over the past four years, we mentored 40 first-year URP students in research over the January interim sessions compared to no URP students in the January interim sessions during the four years prior to our HHMI grant. During the four years prior to our HHMI grant, 13 of our summer research students were from underrepresented populations and this number increased to 28 students during the four years of our grant. Now that our grant is complete, we are continuing a modified Science Horizons Program using internal funds and of the five students participating in the program this year 80% are from underrepresented populations. We anticipate providing summer research experiences to at least two of these students this summer. Our HHMI grant also supported an off-campus summer research program. Over the past two years, we sent ten students off campus to work with mentors at R1 institutions and 50% of these students were from underrepresented populations. Thanks to a significant alumni donation, we are continuing this program and this summer we expect to send four students for off-campus summer research opportunities and 100% of the selected students are from underrepresented populations. To put these numbers into perspective—although the numbers vary from year to year—this year, 20% of our newly declared majors are from underrepresented populations. Finally, during the past four years, we gained our first experience with the Annual Biomedical Research Conference for Minority Students (ABRCMS). A Lafayette faculty member or student was present at three of the four last ABRCMS meetings. Support for student attendance at this meeting is also built into our new Science Horizons Program.

3. **More Biology courses incorporated course-based research.**
   
   One goal of our grant was to infuse half of the biology courses with interdisciplinary approaches. The effect of integrating new, interdisciplinary, problem-based modules in the classroom and laboratory on student learning was assessed using a subset of the questions in the Classroom Undergraduate Research Experiences (CURE) survey. In general, students reported little experience with a project entirely of their own design before the module although they reported much experience in collecting and analyzing data. Following the problem-based module, students reported moderate to large gains in understanding how scientists work on real problems and that scientific assertions require supporting evidence. They also reported that the research project was a good way to learn about the process of
scientific research. Students in one course participated in field-testing the Laboratory Course Assessment Survey. After engaging in the course-based research experience students reported increases in their science identity, science self-efficacy, and science value orientation. Overall, during the year before our grant began 35% of the biology courses with labs used course-based research and in the last year of our grant (2015-16) 66% of biology courses with labs used course-based research; this included our new involvement in the HHMI SEA PHAGES program. During the 2015-16 academic year, these courses enrolled a total of 426 students.

4. **We have more computational biology in our curriculum.**

Another major outcome is that we now have a computational biologist at Lafayette College. Assistant Professor Eric Ho was hired with our grant and has been offering Bioinformatics, Biomedical Informatics and Computational Methods on a regular basis. He also regularly mentors research students in this area and assists students conducting research with other faculty when their research projects involve in-depth bioinformatics such as RNA Seq studies. We also recently received approval to hire a teaching postdoc who has expertise in bioinformatics and health disparities. We are encouraged that we may be able to make an offer to her, which would add to the diversity of faculty in the department.

---

1 Corwin LA et al. 2015. The laboratory course assessment survey: a tool to measure three dimensions of research-course design. CBE—Life Sci Ed 14: ar37.
MAJOR ACCOMPLISHMENTS FOR NON-CAPSTONES

LEWIS & CLARK COLLEGE
Program Director: Liz Stanhope, Associate Professor of Mathematics

The grant sought to prepare future teachers through integrating teacher and undergraduate education in the sciences with the help of a joint faculty appointment in the College of Arts and Sciences (CAS) and the Graduate School of Education and Counseling, engagement of science majors in mentoring high school students, and undergraduate science curriculum development in quantitation.

- Successful adaptation of student recruitment strategies and curricular modification that increased overall participation, and participation of under-represented minority URM students, in all parts of the CELS (Community Engagement and Leadership in Science) Outreach Program. See Figure 1.

- Articles in the local media such as the College alumni magazine and the CAS student newspaper

- Peer reviewed article by Liza Finkel published in the Journal of Science Education and Technology.

- Approximately 40% of academic year, high school CELS students reported gains in understanding the scientific process. The percent of academic year undergraduate CELS students reporting that they learned the steps needed to be a teacher grew from 0% in 2014, to 30% in 2015, to 72% in 2016. In 2016, 33% of academic year undergraduate CELS students reported being inspired to consider teaching as a career. On average summer undergraduate CELS students reported increased interest, confidence, and knowledge about STEM careers and topics.

- Three undergraduate CELS participants have enrolled in the Lewis & Clark Graduate School of Education MAT program. Another has applied. At least two of these students come from backgrounds historically underrepresented in science. In addition about ten high school CELS participants have matriculated as students in the Lewis & Clark College of Arts and Sciences.

- Design and launch of the yearly 100-level mathematics course “Calculus & Statistics for the Life Sciences.” RISC Survey results from 2014 and 2015 indicate expected high perceived learning gains in data analysis in comparison to both SURE survey takers and all RISC survey takers. However, Math 123 students also report learning gains in self-confidence, becoming part of a learning community, and confidence in my potential as a teacher of science comparable to SURE survey takers and higher than all.

1 Finkel L. 2016. Walking the path together from high school to STEM majors and careers: utilizing community engagement and a focus on teaching to increase opportunities for URM students. J Sci Ed Tech 1/2017.

Figure 1. CELS Participation
RISC survey takers. (Figure 2, results from 2015 RISC survey below.)

Figure 2. Learning Gains

- HHMI program leaders were awarded an internal grant to pilot a STEM Teachers Pathway program connecting undergraduate Lewis & Clark STEM students to the Lewis & Clark Masters in Teaching (MAT) program. This work was developed into a collaborative grant proposal currently under review at the NSF to further develop this pathway, including connection to Portland Community College and Portland Public Schools.

- Work in interdisciplinary curricular initiatives has launched a Neuroscience minor, laid the groundwork for a future data science minor, facilitated linked topics in introductory biology and chemistry courses, and has better aligned an introductory chemistry course to serve environmental studies students.
The goal of Luther College’s HHMI grant was to strengthen science education by: 1) preparing secondary education teachers to implement inquiry in their classrooms and develop their identity as teacher-researchers and leaders in science education, and 2) increasing elementary educators’ confidence in teaching science through a variety of inquiry-based educational opportunities in partnership between Luther College and regional schools.

To this end, we implemented an array of programs that sought to expose preservice and in-service teachers to the scientific process and increase their ability to integrate this into K-12 curriculum. We offered financial support to afford future educators the opportunity to expand and strengthen their scientific base by completing an additional year of science courses, along with enabling science majors to obtain the necessary education courses for teaching certification. The grant also allowed preservice teachers to complete their student teaching semester with leading science educators around the world. Our assessment data for these programs, gathered through quantitative and qualitative instruments (e.g., STEBI-B analysis, SURE surveys, interviews, self-assessment tools, institutional data), suggested that these programs served to better prepare future and current educators for teaching science and to be leaders in their field.

While the HHMI award allowed us to successfully implement seven programs targeting K-12 science education, certain programs showed a notable contribution towards the stated goals. One of the foundational components was the HHMI Research Trio Program, which was designed to provide opportunities for secondary science teachers (preservice and in-service) and science/math undergraduates to conduct summer research with Luther STEM faculty. The research trios had several goals. First, we hoped that future and current educators would gain a deeper understanding of science through research, and that the experience would help foster a self-image as a leader in science education. Our assessment results indicated that all participants showed increased understanding of the process of science and the role of problem-solving in doing research, and science educators expressed greater confidence in their understanding of scientific process, and were being asked to provide their skills in a variety of leadership roles at their schools. Second, we viewed the research experience as a mechanism to increase retention of both preservice and in-service educators in science education, and the data was supportive. Third, we developed additional activities related to sharing of scientific experience and knowledge with peers to expand scientific proficiency. We established a “Communicating Science” seminar, in which all undergraduate trio participants met during the ensuing semester to discuss their research and work on how scientific communication takes place. We also provided travel funding and incentives – in the form of delayed stipend distribution – to encourage students to present their research at regional or national scientific or educational meetings. Finally, we implemented daily lunches for all researchers and reciprocal lab visits, thereby enhancing conversations about the potential connections between teaching and research. The assessment results indicated that the communication component was integral for building participants’ confidence in science and their role as leaders.

A second program that demonstrated strong success was the Science Teaching Practicum (STP), which provided preservice teachers with opportunities to enhance their science literacy, teaching skills, and leadership by developing and teaching weekly inquiry-driven science lessons in area classrooms under the supervision of Luther education faculty and cooperating teachers. Importantly, STP participants were challenged to integrate science and literacy instruction – an increasingly important strategy as principals respond to reading test scores by prioritizing literacy instruction. Preservice participants also realized how external standards affect classroom instruction; changing science standards meant that some lessons that worked well previously no longer fit, while state-mandated changes to math and literacy instruction affected classroom science pedagogy, thereby reducing science integration. The assessment results from the Science Teaching Efficacy Belief Instrument (STEBI-B) showed that the STP experience had a positive impact on the preservice teachers’ view of themselves as science teachers. The participants were much better prepared for teaching science, and had a greater literacy in carrying out science projects. They are also better able to strategize how to combine science literacy with science experiments in the classroom. Of note, the program contributed to a strong gain in the number of preservice teachers seeking science certification. Finally, we provided opportunities for our pre-service educators to
attend and present their work at professional meetings for science educators.

A third program that was highly successful was the Summer Science Workshop, which provided week-long experiences for regional teachers to deepen their scientific knowledge and expand their range of inquiry-based lessons through hands-on development of age-appropriate scientific curriculum. The workshop focused on issues such as water quality and plant science, and participants carried out a variety of place-based science experiments, taking part in hands-on activities with field research, along with collecting and analyzing data. These experiments were carefully designed to be easily implemented in the classroom regardless of what resources were at the teacher’s disposal, and structured so they could be modified to convey the scientific concepts relative to each grade level of the elementary curriculum. Teachers were asked to keep a science journal that included all lab data collection and analysis, writing prompts and responses, collective questions, and thoughts throughout the week. Feedback indicated there was overwhelming support for the journal, recognizing it as both a significant teaching resource and learning tool. Throughout the week-long workshop, leaders infused additional examples of direct applications to their teaching, lesson ideas, and extensions. By doing this, participants were able to spend more class time on “doing science” and growing their confidence in their science skills. There was also an intentional emphasis on carving out a greater time for teachers to focus on how to use the Next Generation Science Standards in their lesson development and to collaborate with their peers. Interest in the workshop was far greater than anticipated, and we ended up expanding the program to involved more in-service teachers. The assessment results were similarly strong. Teachers reported an increased confidence in their ability to teach science and indicated that they were much better equipped to do so, both with resources and knowledge. They also felt more strongly that teaching science was important relative to when they arrived at the workshop.

An additional benefit of the HHMI program are the relationships established through these activities. The HHMI grant has served to strengthen the existing connections and establish a new level of collaboration between science and education departments at Luther College. Second, the grant activities have served to both strengthen and establish relationships between Luther College and regional school districts. We continue to have requests for preservice teachers to teach the lesson plans developed through the grant, and regional teachers regularly ask to use our science materials and consult with us as to how they should address specific scientific topics.
HHMI funding allowed Macalester College to increase the capacity of students and faculty to transform data into scientific knowledge through computation, and to share that knowledge with others; and increase institutional understanding of and support for underrepresented students in STEM disciplines, including students of color, first-generation, and Pell-eligible students.

**Data Science:** Two grant-funded programs supported the development of faculty and students to manage and create meaning from data sets of increasing size and complexity.

1. *Faculty development through a summer Computation and Visualization Consortium (CVC) workshop:* The workshop was developed with the purpose of broadening knowledge of data science among faculty and staff at a multiple institutions. This weekend course, developed by Danny Kaplan (Macalester), Randy Pruim (Calvin), and Nick Horton (Smith, now Amherst), has had over 90 participants from 34 institutions during the last three years. Almost half (42) of the faculty come from math, statistics, or computer science backgrounds, with the rest from biological, social, and physical sciences. The workshop has evolved with feedback from participants into 2.5 days of hands-on activities and teaching, and 2.5 days of intensive individual or institutional ‘projects’ of participants’ choosing, with tutorial support and reporting back to the larger group. Faculty at the workshops share descriptions of their individual or group projects, as well as links to these materials, with the other CVC participants each year. These materials have also been made widely available to the Rstudio user community through Github. Participants reported very high satisfaction with the workshop and an increased interest in and ability to work with large data sets using R and Rstudio. In a related endeavor, Kaplan and colleagues have garnered NSF funding through the Mathematical Association of America to continue this work in training faculty to teach student workshops (StatPrep grant/program, statPreP.org).

2. *Student engagement in Big Data through Data Science courses:* Over the last several years, a 1-credit Data and Computation Fundamentals (DCF) course has been offered every semester at Macalester. Broad interest from students and high enrollments in the DCF course as well as other math/statistics/computer Science (MSCS) courses has led to an expanded vision of data science at Macalester. Four tenure/tenure-track faculty are collaborating in 2017 to transform the current DCF course into a 4-credit offering entitled “Introduction to Data Science.” The goal for the transformation is for the group to develop enough activities and materials that all of them will be capable of teaching the 4-credit course regularly, establishing it as one of the four core introductory courses in the department (alongside applied calculus, statistics, and computer science). Three sections of the course will be offered by two faculty during the next academic year.

In part because of HHMI grant support, Macalester has emerged as a national leader in undergraduate data science education. The student club Data Science for Social Good (DS4Good) meets weekly for an hour to offer tutorials to each other, and then for longer sessions monthly or so to work on an annual project. This year’s project was for MetroTransit, our local transportation service provider. Students will continue to collaborate with local community organizations or neighborhood associations to analyze data about topics such as homelessness, crime, waste, and energy consumption. Student groups also participate in the DataFest (national) and MinneMUDAC (local) competitions. Driven by students’ grassroots interest in data science, Macalester introduced one of the first undergraduate data science minors in the country in fall 2015. The data science minor builds on the strengths of the MSCS department, and is extraordinarily cross-disciplinary in nature. The requirements for the minor include two statistics courses, two computer science courses, two courses from a domain area, and a final integrative essay that discusses a completed data science project or proposes an integrative project in the domain area. It is well-aligned with another college priority, the Digital Liberal Arts. The minor serves as a model for a number of our peer liberal arts colleges who are currently in the planning process to start similar programs; peers such as Smith, Denison, Marquette, and Wesleyan have all introduced data science or data analytics minors, majors, or certificates in the past year (https://www.macalester.edu/academics/mscs/majorsminors/#program-2526).
Support for underrepresented students: The Young Researcher (YR) program aims to increase the persistence of students in STEM. The targeted students are early in their undergraduate career with no research experience who identify as belonging to an underrepresented group, first in their family to attend college, or who might be less well-prepared (e.g., from a rural or urban school that doesn’t offer AP courses). Feedback and an increasingly diverse group of applicants over the course of the grant allowed us to focus on students with only a year of college experience. The program provides students a ten-week mentored summer research experience with a cohort of other YR students in a lab working directly with a faculty member and an undergraduate peer mentor. Additional summer and academic year programming includes presentation of their research at a summer research poster session on campus, panel discussions with current graduate students, and social outings and activities with their research mentors. Students participating in the YR program report overwhelmingly positive research and mentoring experiences, and more than 90% of the students (all but 2 of 25) who participated in the program over the past four years will (or are on track to) graduate with a STEM major. Conversations with all YR mentors after year 3 provided guidance and advice for the YR faculty member in year 4, and her feedback (along with student interviews) encouraged us to try a larger cohort in multiple labs. Longitudinal support for the YR program resulted in an increase in the number of applicants that were an excellent fit for the program criteria, and an increase in the number of faculty who nominated themselves to offer a YR program. In addition, all but one student in the first three cohorts completed a STEM major.

The YR program has helped raise faculty awareness about the key role of advising and mentorship in supporting all students. Faculty development around advising non-traditional students is currently a focus of the Provost’s Office and the Serie Center for Scholarship and Teaching (2016-17 is the “Year of Advising”). In the last year, faculty voted to include ‘advising’ as part of faculty teaching expectations (rather than service), making it more likely that faculty will assess and develop their advising practices. Through an Arthur Vining Davis Foundations planning grant, Macalester will host a summer ‘bridge’ program in 2017 to support incoming students from underrepresented groups on campus. A spring 2017 faculty learning community for STEM faculty is discussing best practices regarding teaching and mentoring non-traditional students, particularly at the introductory course level.
Millsaps College’s Cultivating Scientific Habits of Mind through Interdisciplinary and Scientific Competencies resulted in the following major accomplishments:

Development and implementation of a competency-based, concept-driven curriculum reinforced and enhanced with research experience. We developed a three-course interdisciplinary laboratory sequence to integrate genetics, molecular cell biology, and biochemistry. Laboratory experiences in these courses were based on original research. A total of over thirty students have participated in some or all of the sequence. An assessment survey modeled after some aspects of the grit test from Angela Duckworth was developed to assess critical thinking, competency, confidence, and grit. This assessment was administered to students who took all three courses in the sequence versus students who had only taken Genetics or part of Molecular Cell. The initial results indicate that the only significant difference resulted in the area of competency in which the sequence students exhibited a higher knowledge of material and were better at problem solving than the non-sequence students (p-value < 0.05), 58 ± 29% vs. 21 ± 21%. A major outcome of this work has been the movement across departments on campus to develop courses aimed to cultivate the development of competencies combining lab and lecture portions of courses.

Pedagogical approaches were developed in the fields of biology/chemistry and chemistry/physics that required student collaboration to establish common competencies across disciplines. This guided inquiry, interdisciplinary approach focused on critical thinking, data acquisition and analysis, graphics utilization, research design, and quantitative statistical skills to reinforce the connected nature of science.

An HHMI Scholars program was developed for students to conduct research under the direction of a faculty mentor. Initial assessment of the research program shows an approximate 50% increase in the number of undergraduate students participating in research activities with Millsaps faculty and delivering presentations at scientific meetings. HHMI Scholars engaged the larger scientific community through participation in an expanded symposium sponsored by the Millsaps Tri Beta honor society and through the development of a new and separate undergraduate research symposium at the Mississippi Academy of Sciences. This symposium is now part of the Mississippi Academy of Sciences Annual Meeting and the MAS has agreed to continue supporting this symposium financially at the conclusion of the grant.

Changes in the culture of Millsaps College have taken place due to this grant. The College is using our new pedagogical sequence as a recruiting tool for prospective students. In addition, we are now using a competency based model for all our intro science courses and adopting a very similar model for our freshman course Ventures, required of all incoming students. Because of the increased number of students participating in summer research programs, the administration has revised policy and is starting to subsidize summer housing. Finally, the College has taken a more pragmatic approach to faculty teaching labs and agreed to count a 1 credit hour lab the same as a 3 hour lecture course.
We developed three sequential introductory biology course-based research experience (CRE) labs, which over 4.5 years have permitted 1,118 students to have a minimum of a one semester research experience. This was >90% increase from the number of opportunities previously available at our institution, compared to ~2% of students who participated in summer internships.

Across all three CREs, students exited rating their perceived gains highest across five categories which are listed in Table 1 below. When comparing the top five categories in our interdisciplinary course, there is overlap in one area, the ability to analyze data and other information.

Table 1. Course Impacts That Students Report Experiencing Highest Gains

<table>
<thead>
<tr>
<th>Course Element</th>
<th>% of Students Rating High Gains</th>
<th>Course Element</th>
<th>% of Students Rating High Gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning laboratory techniques</td>
<td>77.4%</td>
<td>Learning to work independently</td>
<td>82.1%</td>
</tr>
<tr>
<td>Ability to analyze data and other information</td>
<td>76.3%</td>
<td>Interpretation of results</td>
<td>74.8%</td>
</tr>
<tr>
<td>Understanding science</td>
<td>72.4%</td>
<td>Understanding how knowledge is constructed</td>
<td>71.4%</td>
</tr>
<tr>
<td>Understanding of how scientists work on real problems</td>
<td>71.8%</td>
<td>Calling upon your personal values to motivate the study of a problem or problems</td>
<td>69.4%</td>
</tr>
<tr>
<td>Understanding that scientific assertions require supporting evidence</td>
<td>71.6%</td>
<td>Ability to analyze data and other information</td>
<td>66.4%</td>
</tr>
</tbody>
</table>

Students who have completed more CRE labs than traditional labs accounted for only 38% of all DFWs in General Biology III, our capstone CRE course. However, their peers that have completed more traditional labs accounted for significantly more DFW, 63% (p=0.024).

We developed an interdisciplinary (biology, chemistry, geospatial/environmental sciences, math and music) course (STEM 1200) which over a two-year period has provided scientific literacy to 249 non-majors. There is significant demand for this course and the number of sections offered has increased four-fold over the two years of it being offered. It has improved students’ interest and aptitude for math by utilizing a virtual stock market model which enables students to establish and maintain an account.

Through our CREs, we have introduced the model of Peer Led Team Learning (PLTL) to our university. This element of the grant has been well received and the University has offered to support this component for the biology department.

Seven faculty development workshops were offered to approximately 110 STEM faculty on topics such as: Science Education Policy –National to Local, Curriculum Development, How to be a Good Mentor, Faculty who Team Teach STEM Courses for the Millennials, and Metacognition: Teaching Students Transformative Learning. Faculty representation was across all five of our science departments: biology, chemistry, environmental science, mathematics and physics, and pharmaceutical sciences.

Dr. Sandra McGuire’s workshop on Metacognition with our faculty was one of the most successful implemented during our funding period. The faculty members’ (n=15) mean ratings were the highest possible (5.0 on a 5-point scale) for nearly every item on the survey. For example, 100% of the faculty strongly agreed that they planned to use the information and ideas from the workshop in their work with students. Faculty have also used their involvement in the HHMI grant as a launching point for delving more into learning about innovative
teaching methodologies/techniques. Open-ended survey comments such as “Dr. McGuire explained metacognition in ways that I can relate unlike other workshop presenters” and “Professors have an impact/responsibility to student learning that is quite significant, as significant as the students’ own responsibility for learning!” are two specific examples that indicate how faculty members were impacted by the workshop.

• We also co-sponsored a Summer Faculty Institute focused on curriculum development in STEM and bridging the gaps in academic understanding in science, based on our student achievement data. Eight STEM faculty (2-3 representatives from each of the STEM departments) participated in the nine-day institute where they received intensive training on curriculum development, formative assessment, and universal design for learning and understanding diverse learners.

• As a result of attending a CRE workshop, one faculty in chemistry was inspired to develop a course to enhance student learning in analytical chemistry through a CRE. A majority of students reported increased confidence in their lab skills, technical skills, analytical skills, and communication skills. Retention and pass rates of students in this project-based analytical chemistry course were significantly higher when compared to students who previously took this course with non-project-based activities. This instructor subsequently received an HBCU-UP mini grant to further develop this course. One peer-review publication resulted from this course development.¹

• Fifteen faculty participated in ‘NCCU-led’ invited workshops at national meetings. All workshops focused on courses we developed. Of note is that for a workshop to be held, a minimum number of registrants was required. Over the past 4 ½ years, our faculty have had 19 presentations, of which 5 were invitational. We have several peer reviewed publications,² 1 NAS conference report, 1 under review (HHMI CRE collaborative), and 1 under revision for resubmittal (NCCU).

---


² Staub NL et al. 2016. Course-based science research promotes learning in diverse students at diverse institutions. CUR Quarterly 37: 36-46.
The College sought to establish the Center for Learning, Education, and Research in the Sciences (CLEAR) as a mechanism for enhancing problem solving throughout the science curriculum and for fostering cross-departmental collaboration. CLEAR supports:

- Peer-led activities that focus on quantitative skills and scientific problem solving – including CLEAR drop-in hours staffed by trained undergraduate mentors, course-based peer mentors for introductory courses that can be barriers to persistence in STEM, and cross-cutting skill workshops on topics such as graphing with Excel or using LaTeX for math or chemistry—and that build the skills of tutors as well as tutees;
- Curricular changes that increase students’ capacity in scientific problem solving, quantitative reasoning, and interdisciplinary approaches; and
- Faculty/curriculum development workshops to expand students’ exposure to and proficiency in the skills and approaches listed above.

Now in its fourth full year of programming, CLEAR is a core component of the sciences at Oberlin. The Oberlin Workshop Learning Sessions (OWLS) supplemental instruction program now supports approximately 20 classes per year and is highly regarded by faculty and students, with being an OWLS mentor seen as a desirable student leadership position. Launched in September 2013 in the science library, the Quantitative Skills (QS) Center has since expanded to two additional locations on campus. After a start-up period in its first year of operation, the Center since fall 2014 has served at least 100 individual students per semester, with 200 to 300 visits each semester. Peer-learning approaches have been shown to benefit all students and be of particular value for underrepresented minorities (URM), and since fall 2016, the percentage of URM OWLS leaders and QS tutors has exceeded Oberlin’s overall URM enrollment. In addition, 60% of the OWLS leaders and QS tutors were women.

In general, students who attend OWLS regularly receive higher course grades, with improvements up to a full grade step higher in certain classes. DFW (grades of D, F, or withdrawal) rates in courses served by OWLS have also fallen. The most-frequent attenders of OWLS sessions often go on to become OWLS leaders, advancing Oberlin’s aim of leadership development. In reflections about their experiences, OWLS leaders frequently noted: improvement in their ability to speak in public, to facilitate groups, to teach, and to practice leadership skills; better understanding of the course material; broader perspectives of their own learning; and improved ability to explain complex scientific concepts.

QS tutors frequently noted a sense of satisfaction in helping students solve their own quantitative problems and lower their anxiety. Students who visited the QS Center multiple times reported that they most valued their increased understanding of course material after consultations with QS tutors, better performance on exams, encouragement from tutors, and getting to know the tutors. The academic and broader benefits of these peer-mentoring initiatives are recognized by faculty, who report that OWLS represents an interdisciplinary cohort of peer educators that facilitates community among different majors.

Over the grant period, curriculum-development grants have supported the launch or revision of 28 science courses. These range from quantitative skills-oriented seminars for first-year students and revised introductory physics labs, to upper-level courses in biochemistry, biology, geology, mathematics, neuroscience, statistics, environmental studies, and psychology. Courses revised or developed through the grant continue to be offered, ensuring a lasting impact on the curriculum. Many of the revisions involve interdisciplinary themes. Four sets of supported courses involve faculty from more than one department. CLEAR has required an assessment plan for all funded courses and aided faculty in their assessment efforts, approaches which helped to build a positive view of assessment that will extend beyond the grant period.

One of the key features of Oberlin’s program is that all STEM departments are stakeholders, facilitating internal dissemination and sharing of best practices. A website (http://new.oberlin.edu/office/clear/) and annual newsletter available on the website share CLEAR’s activities and vision with students, faculty, the campus community, and external audiences. A video about the OWLS program is available at: http://new.oberlin.edu/office/clear/for-students/owls/index.dot.
CLEAR has sponsored faculty workshops with national leaders such as HHMI Professor Isiah Warner (Louisiana State University), Eric Gaze (Bowdoin; President of the National Numeracy Network), and Mary Pat Wenderoth (University of Washington, author of pioneering studies on active learning). Student workshops have focused on skills and programs such as graphing in Excel and using R and Nova for statistical analysis and modeling. As the grant progressed, these workshops were increasingly run by students.

A partnership—among CLEAR, Oberlin’s multicultural resource center, and program on gender, sexuality, and feminist studies—led to establishing an ongoing series of events on science and society called Roots & STEM. It has featured faculty and student panels and guest speakers on topics including women in STEM, science communication, and science and social justice. Beyond the series, these and other collaborations have enabled CLEAR to help lead and work in close coordination on programming around diversity and inclusion across campus. To increase awareness of student research on campus, CLEAR also organizes a cross-campus research open house each year and co-sponsors Oberlin’s annual symposium on undergraduate research.

Assessment of the grant has included: a) ongoing tracking and analysis of student use of the quantitative skills drop-in center, OWLS sessions, and skills workshops; b) evaluation of courses revised/initiated through curriculum-development grants; c) analysis of patterns of student progress and persistence in STEM fields at Oberlin in total and in relation to grant activities; d) comprehensive analysis of the cohort of students entering fall 2013 over a four-year period through spring 2017; and e) administration of two validated instruments. The Quantitative Literacy and Reasoning Assessment (QLRA), a field-agnostic test of quantitative skills, and the Biological Science Quantitative Reasoning Exam (BioSQuaRE), a test of quantitative skills in a biological context, are being administered in BIOL 100 (Introductory Biology) each year. The QLRA is also being given each year in classes taken by students who have completed BIOL 100, to assess learning gains over time. BioSQuaRE has been developed through an HHMI-supported collaboration that includes Oberlin Program Director Jason Belitsky, CLEAR Director Marcelo Vinces, Assessment Coordinator Tabassum Haque, and colleagues at ten other colleges and universities.

Results from these ongoing quantitative assessments and qualitative feedback from students and other stakeholders show that the grant activities are achieving their objectives. Analysis of the assessment data is in progress for publication.
Together, as a strong collaboration between the SFSU SEPAL: The Science Education Partnership & Assessment Laboratory and the SFSU Department of Biology, we implemented Biology FEST – Biology Faculty Explorations in Scientific Teaching, a multi-pronged faculty development program that enhanced faculty pedagogical expertise, supported iterative change in biology teaching, engaged faculty in regular discussions of student assessment evidence, and built infrastructure to support comprehensive curricular reform in the future (Figure 1). The overarching goal of the effort was to produce students who are scientifically curious and literate leaders in society regardless of their eventual career emphases.

“During Biology FEST, a colleague reminded us that in research we re-tool and learn new techniques all the time. Why wouldn’t we bring that same kind of creativity and commitment to our teaching?”

Faculty participation in the Biology FEST Scientific Teaching Institutes and follow-up programs was extremely strong. Out of the total of 39 tenured and tenure track faculty, 90% (35 of 39) participated in a five-day Biology FEST Institute. In addition, 87% of our lecturers (20 of 23) also participated in the five-day Biology FEST Institute. Overall, 89% of the department as a whole (55 of 62 instructors) participated in the Biology FEST Institute. Similarly, participation in follow-up programs was also strong, especially given the significant time commitment required for these activities. Also, to be eligible for a follow-up program, instructors had to have attended an Institute—where they explored assessment, active learning, equity and diversity, and classroom evidence collection—and be teaching a class during the term when the follow-up program was offered (Figure 2). For all follow-up programs offered, we had over 80% of eligible instructors involved. In summary, we had a very high participation rate for faculty involvement in pedagogical training for a single STEM department, which addressed all four original aims of our proposal.
2. Students corroborated faculty reports of faculty implementation of scientific teaching

“In my 4th year at SFSU, I have seen a huge improvement in the equity climate in my science learning...using this semester as an example, most of my biology classes operate in similar ways that feel more equal than semesters before. In 3 of my 5 classes, we use name cards with reflections. We use clickers. And we perform a lot of think-pair-shares. All 5 instructors actively try to connect our learning to outside world examples (via clinical scenarios, jokes, cartoons, articles, etc.), and instructors are really trying to encourage students not to be afraid of the material, to try endless number of ways to learn the material (post videos, animations, practice problems, practice exams, etc.), and to understand concepts, not memorize details.” – SFSU biology undergraduate student

Additionally, student reports on our annual Student-Faculty Classroom Perceptions Survey have persistent-ly corroborated faculty reports of the frequency of use of active learning for three years running, suggest that faculty are persisting in their implementation of scientific teaching.

3. Our faculty community developed and published a novel predictor of teaching practices that moves beyond only lecture–direct measurement of classroom noise

HHMI Biology FEST faculty participants reported extensive implementation of scientific teaching through their submissions of written reflections and presentation of informal posters at the end of the semester after they attended a SEPAL Scientific Teaching Institute. However, self-reports of pedagogical change by faculty can be varied in accuracy. As part of our effort, faculty collaborated with SEPAL Postdoctoral Scholars to audio-record all class sessions in their courses for noise analysis using a newly developed DART (Decibel Analysis for Research in Teaching) tool, which was published in collaboration with dozens of faculty co-authors in March 2017¹ and for which a patent is pending. Figure 3 shows how class sound reflects differences in teaching strategies used in lecture-only versus scientific teaching classes. In Figure 4, analysis of 32 courses taught in a single semester by HHMI Biology FEST faculty showed that 22% of courses analyzed included some form of active learning in every class and 81% included some form of active learning in at least half of the class sessions, suggesting significant progress on the original aims of our proposal.

¹ Owens MT et al. 2017. Classroom sound can be used to classify teaching practices in college science courses. PNAS 114; 3085-90.
The overarching goal of our HHMI grant was to transform the teaching of science at Southwestern University to incorporate the process of discovery at all levels so that we may increase the success of our students and ultimately generate a creative, accomplished, and diverse pool of future scientists.

To accomplish this goal, we created the Inquiry Initiative, a comprehensive program to support the incorporation of active and inquiry-based learning within all levels of our undergraduate science and math curriculum. Specifically, our HHMI-funded programming centered on the following objectives, and we highlight our major accomplishments for each below.

**Transform all of our introductory and upper-level science and math courses using active and inquiry-based learning and course-based research experiences**

- Southwestern faculty transformed their classes by creating active learning modules during our summer pedagogical workshops. Our faculty were enthusiastic and quick to incorporate inquiry-based components into their courses and by the end of our fourth grant year, 30 different faculty had created a total of 102 active learning course modules for 58 laboratory and lecture courses. Curricular transformation was widespread and evident in every discipline and at all levels (Figure 1).

- All of our introductory science laboratory courses—which were previously based on “cookbook” experiments—were completely revised. For example, general chemistry is now wholly inquiry-based and centered around semester-long research projects. Analysis to characterize the “level of inquiry” of lab experiments shows that the revised chemistry curriculum exhibits a higher level of inquiry (2.5, on a rating scale where 1 = confirmation experiment and 5 = research-based inquiry) than the previous traditional curriculum (inquiry rating = 1.6).

- We quantified the amount of active learning occurring in both revised and unrevised classes using the Teaching Observation Dimensions Protocol (TDOP). Results show that lecturing decreased in courses that were revised to include active learning modules. Southwestern science and math students now spend substantially more class time actively engaged in small group work and interacting with their peers (Figure 2), activities that are strongly correlated with increased student success.

**Implement an inquiry-based curriculum within Organic Chemistry to address student retention and success within one of the most important “gateway courses” in the sciences**

During our HHMI grant, we hired a tenure-track organic chemist and a staff member with faculty rank to direct our organic laboratories. Both participated in our summer pedagogical workshops annually and...
major accomplishments for non-capstones

worked collaboratively to completely revise Organic Chemistry to an inquiry-based curriculum. For example, TDOP data collected in the revised Organic Chemistry lecture reveal that lecturing significantly decreased while small group work, peer interactions, and problem solving occur significantly more often when compared to unrevised courses (Figure 3).

- SCOPE students present their research to the campus community during the Science Research Open House, an annual event that has continued past the award period with institutional support. The number of Southwestern students making presentations at regional and national scientific conferences increased substantially with creation of the SCOPE program (Figure 4).

![Figure 3. Percentage of two-minute TDOP intervals coded in revised Organic Chemistry and unrevised courses.](image)

![Figure 4. Number of students presenting at regional or national conferences during each year of Southwestern's HHMI award.](image)

- Create an inclusive and diverse science community through group learning strategies, support networks, and ongoing programming
- Annual workshops on topics such as racial climate, stereotype threat, gender bias, and inclusive pedagogy provided consistent opportunities for faculty development.

- SCOPE experienced tremendous growth during our HHMI grant (Table 1), with the fourth year being the largest and having the most diverse group of participants in the program's history. Notably, the number of female and underrepresented minority students more than doubled from the first to fourth year.
- SCOPE expanded research opportunities to disciplines outside the life sciences (e.g., math, computer science, psychology).

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty</td>
<td>16</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>67</td>
</tr>
<tr>
<td>Disciplines</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Students</td>
<td>30</td>
<td>36</td>
<td>39</td>
<td>43</td>
<td>148</td>
</tr>
<tr>
<td>Female</td>
<td>15 (50.0%)</td>
<td>22 (61.1%)</td>
<td>24 (61.5%)</td>
<td>30 (69.8%)</td>
<td>91 (64.5%)</td>
</tr>
<tr>
<td>URM</td>
<td>7 (23.3%)</td>
<td>12 (33.3%)</td>
<td>10 (25.6%)</td>
<td>17 (39.5%)</td>
<td>46 (31.1%)</td>
</tr>
</tbody>
</table>

Table 1. Participants in SCOPE. Disciplines include animal behavior, biology, chemistry/biochemistry, computer science, kinesiology, math, physics and psychology. Underrepresented minority (URM) students include Hispanic, Black/African American, American Indian or Alaskan Native, and Native Hawaiian or Pacific Islander.
• We created a Supplementary Instruction program, led by upper-level “SCI Guide” peer mentors. SCI Guide sessions became an important tool in improving student retention and achievement, and Southwestern now fully supports this program.

• Our efforts to increase women and underrepresented minority (URM) students in the sciences have already yielded significant results. Table 2 shows the number of declared majors in science disciplines for summer 2013 (before implementing our new curriculum) and fall 2015, after revision of 32 science and math courses. The percentage of URM students nearly doubled across all majors during this two-year span while the number of women declaring majors in disciplines such as chemistry/biochemistry, computer science, math, and physics also uniformly increased.

<table>
<thead>
<tr>
<th>Major</th>
<th>2013</th>
<th></th>
<th></th>
<th>2015</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Students</td>
<td>Women</td>
<td>URM</td>
<td>Students</td>
<td>Women</td>
<td>URM</td>
</tr>
<tr>
<td>Biology</td>
<td>71</td>
<td>50 (70%)</td>
<td>16 (23%)</td>
<td>76</td>
<td>49 (65%)</td>
<td>30 (40%)</td>
</tr>
<tr>
<td>Biochemistry &amp; Chemistry</td>
<td>24</td>
<td>9 (38%)</td>
<td>2 (8%)</td>
<td>33</td>
<td>19 (55%)</td>
<td>6 (18%)</td>
</tr>
<tr>
<td>Computer Science</td>
<td>19</td>
<td>2 (11%)</td>
<td>3 (16%)</td>
<td>23</td>
<td>10 (44%)</td>
<td>7 (30%)</td>
</tr>
<tr>
<td>Math</td>
<td>10</td>
<td>4 (40%)</td>
<td>1 (10%)</td>
<td>19</td>
<td>9 (47%)</td>
<td>4 (21%)</td>
</tr>
<tr>
<td>Kinesiology</td>
<td>23</td>
<td>15 (65%)</td>
<td>2 (9%)</td>
<td>41</td>
<td>21 (51%)</td>
<td>11 (27%)</td>
</tr>
<tr>
<td>Physics</td>
<td>14</td>
<td>4 (29%)</td>
<td>3 (21%)</td>
<td>18</td>
<td>7 (40%)</td>
<td>4 (22%)</td>
</tr>
</tbody>
</table>

Table 2. Declared majors (rising juniors and seniors) in summer 2013 and fall 2015 unrevised courses.
St. Olaf pursued three major imperatives under the auspices of its 2012 award from HHMI: (a) increase persistence and success in STEM, especially by students in underrepresented groups; (b) enhance opportunities for interdisciplinary research and learning, both within STEM disciplines and with the social sciences and humanities; and (c) preparation and development opportunities for pre- and in-service science teachers through a joint faculty appointment in education and biology. Previous HHMI awards, dating to 1988, laid the groundwork to accomplish them. Both imperatives reflect the strategic priorities of the college and the requests St. Olaf makes of external funders.

**Persistence in STEM**

- **Summer Bridge** at St. Olaf began in 1988. It enables 40-45 entering students to gain familiarity and confidence as the first in their family to pursue a bachelor’s degree. Also participating are students of modest economic means and those from racial or ethnic groups underrepresented (URM) at St. Olaf. During the four-week session, summer bridge students attend conventional class sessions and learn their way around the laboratory. The approach is integrative, building skill in writing, quantitative reasoning, guided research, note-taking, and test taking. As they discover and extend the range of their academic skills, students form bonds with each other and with two STEM faculty, one writing professor, and 15 peer tutors. Bridge students also work closely with five professional staff. These staff members support the students to graduation, as bridge students’ additional leadership and STEM mentoring programs.

- From 1996 to today, the percentage of participants who are not white has increased from 70% to 90%. The graduation rate (since 2002) for all Bridge students is 82% vs. ~87% for students overall.

- For the graduating classes of 2013-2016, 46% of URM students who participated in Summer Bridge graduated with a degree in STEM. This is almost equal to 51% STEM for all students at St. Olaf.

- The value of Summer Bridge at the College has been recognized. Funding from the College and other sources is >70% of total current program costs. Funding from HHMI is ~30% of total costs.

- Quantitative Reasoning (QR) skills are a key to success in STEM. Bridge student scores on the BIOSquaRE assessment of quantitative reasoning fall ~2 SD below the national average. We introduced 2-3 hours per week of in class problem solving, Excel training, and data visualization to enhance QR skills. Bridge students also conduct simple analyses of data they generate themselves, so they learn about the validity of quantitative data as well as the generalizations drawn from them. We are tracking the path/success of students in STEM who completed this training as they progress through their education.

- In 2015, we shifted eight hours of attendance in class/lab to inquiry-based learning, completed as part of a research team under the direction of a faculty member. In 2016, bridge students investigated heavy metals in the environment, and drew explicit connections to the water crisis in Flint, Michigan. Teams of 3-4 students collected water and soil samples from various campus locations and tested water their families sent to us. Students said they appreciated the addition to test the water that their families were drinking as well as the water they would be drinking while students. Results of these and other research projects are presented by the students as posters to the campus community on the last day of bridge.
• **Research Opportunities for Sophomores in Science (ROSS)** continues the inquiry-based learning for 10-12 sophomores each summer. ROSS is targeted at first generation, low income, URM students interested in STEM; the majority of applicants participated in BRIDGE the previous year. Overall, very few students at St. Olaf, regardless of background, have the opportunity to engage in summer research after their first year so this is a pretty unique opportunity. Science faculty members co-lead ROSS with faculty in math, statistics, and computer science. ROSS inquiries range from analysis of energy and occupant data generated by our LEED certified science building to quantitative analysis of prairie ecology. Common to all of these projects is data analysis using R or other statistical software and presentation of results to the broader campus community. Through ROSS, participants learn how to read and write science. Many ROSS students end up as science TAs for Bridge.

• A total of 46 students completed the ROSS course from 2013 to 2016 (59% female and 41% male). Of this group, 36 have declared a major and 69% of these students have declared a STEM major. We are tracking the persistence and success of these students relative to URM students who did not participate in ROSS.

• We found that 83% of the ROSS students took a statistics course after completing ROSS vs. 17% before ROSS.

• **Academic Year Research Teams.** In 2016, we developed this program for first-year and sophomore participants in Bridge or ROSS. Twelve students worked in research faculty-led teams of 3-4. Students earn their work-study award as researchers, which means they spend regular hours in the lab, attend lab group meetings and participate in discussions of the primary literature. Each research team includes a junior or senior peer mentor with previous research experience in the lab of the faculty researchers.

• Multiple students who complete academic year research assignments have been awarded summer research opportunities on and off campus.

• Faculty members report strong gains in confidence by students as they learn basic lab skills and become conversant with the scientific literature.

• All faculty participants are enthusiastic to continue this steady mentoring of students as members of their research teams.

**Interdisciplinary Research and Learning**

HHMI grants have been key to the strong interdisciplinary ethos in STEM at St. Olaf, including: (a) the year-long combined biology-chemistry introductory sequence; (b) the integration of biology concepts in introductory physics; (c) establishment of a neuroscience program; and (d) the summer undergraduate research program that serves 123 students on and off campus.

• **First Year Writing (FYW)** is required of all entering St. Olaf students. Prior to the 2012 HHMI grant,
only one STEM faculty member had offered a FYW course. The absence of scientists from FYW reinforced the separation of writing from science and made science less approachable for many students. It also meant that STEM faculty lacked first-hand knowledge of how students advance their writing skills.

- Eleven faculty participated in FYW faculty workshops and seven of them taught at least one section of FYW.
- Faculty reported that participation in FYW resulted in "a much greater appreciation for the diversity in writing abilities of incoming students" and encouraged them to employ scaffolding and other approaches to change how they teach writing in their science classes.
- We developed and taught two offerings of Integrated Science and Society. These courses help STEM majors as well as junior and senior non-science majors consider how scientific investigation and findings shape public policy, private investments and human welfare.
- Addiction: From the Brain to the Social was team-taught twice by a neuroscientist and a sociologist. 44 students took the course.
- The students that enrolled in this course were evenly divided between sophomores, juniors and seniors. Their declared majors ranged from Asian studies to women and gender studies, with ~30% STEM majors.
- In a survey distributed at the end of courses, at least 90% of students reported that their experience in this course contributed positively to their general education learning outcomes including understanding of the process of science and the ability to use different disciplinary perspectives.
- Introduction to Public Health is currently being team taught by a biologist, economist and statistician.
- We hired a Science Educator jointly appointed in biology and education departments. The position has been institutionalized. HHMI support was key to her work with students intending to teach science at the K-12 level. The Science Educator has also convened workshops for middle school science teachers so that students gain a surer grasp of STEM before they enroll at St. Olaf. The most recent workshop focused on incorporating research on monarch butterflies and milkweeds into the classroom. Teachers participating in the workshop were enthusiastic, for example “I am very excited about this research project and the opportunity for students to engage in citizen science.”
A New Generation of Science Professionals. The goal of the Tougaloo-HHMI Program is to prepare undergraduates to become leaders in scientific research and medicine through strategies including development of research experiences in courses and with an individual faculty mentor, interdisciplinary course development, and faculty learning communities. The overall summative assessment revealed three major achievements:

Early exposure to a cohesive two-year research program enhances the academic and personal growth of students.

• Outputs (activities) comprised year-round interdisciplinary research and internships for 29 scholars, local, regional, and national research presentations, publications, peer and faculty mentoring, MCAT/GRE prep, and outreach to local public schools.
• Qualitative outcomes included student skill development in independent research and public presentations, learning about info needed for grad and professional studies, pipeline established to professional schools, and improved MCAT/GREs scores.
• Quantitative outcomes included a >50% increase in numbers of undergraduate researchers, >90% increase in numbers of freshmen or sophomores participating in research, 100% increase in the numbers of research presentations by students, and 25% increase in numbers of students advancing to PhD or professional programs, compared to entire STEM graduating class.

Research and interdisciplinary based curriculum helps students deepen and retain their knowledge.

Outputs (activities) comprised courses revised to incorporate research (7), interdisciplinary modules (3), and flipped classes (10).

Qualitative outcomes were improved academic performance, deeper understanding of quantitative analysis in science, realization of the benefits of teamwork, and learning gains reported in SURE Survey (Figure 1).

Quantitative outcomes included an increase from 10 to 500 students enrolled in CREs and 20% increase in pass rates.

Ongoing faculty development enhances effective science teaching.

• Outputs (activities) comprised faculty pedagogy workshops and competitive seed grants for research with students.
• Qualitative outcomes included increased collaboration among the science departments and providing the impetus to revise all non-majors science courses.
• More than 50% of natural science faculty participated in the development opportunities.

Figure 1. Pre- and post-course comparison for 25 elements in the CURE Survey between TC students in three CREs and All Students (nationally)
Development of a model to incorporate research experiences into a science teacher preparation program, followed by incorporating research experiences in precollege science curricula with successful transfer of knowledge and skills to precollege students.

Science pre-service teachers were trained in microbial ecology theoretical concepts and laboratory skills (induction) and engaged in research for two semesters (immersion) in Research Experiences for Teachers (RET). A summer academy was offered for each cohort, where in-service and preservice teachers designed activities to be carried out in the schools as part of the pre-practicum teaching experience (integration). In a pre-practicum course, the following semester pre-service teachers acted as research mentors to precollege students (transfer of knowledge). A total of 45 pre-service teachers participated in the project (see table below). Most completed the pre-practicum course impacting over 700 students from three elementary, three intermediate and three high schools; 15 in-service teachers were directly impacted. The research activities refined during the summer academy were incorporated into teaching units that were aligned with the content standards of the Puerto Rico Department of Education and National Science Teachers Association. A total of 20 teaching units were developed with measurable learning objectives and assessment tools. Of these units, 16 activity manuals with integrated instructor guides were developed for the students with the pedagogical and scientific processes aligned. Some teachers incorporated a research component into their teaching practices, as evidenced by their course syllabi and their incorporation of six learning units that students used in microbial ecology. In other cases, some of the research-oriented activities developed for the teaching units were incorporated.

### Participation in the RET Program by Cohort

<table>
<thead>
<tr>
<th>COHORT</th>
<th>Academic Year</th>
<th>Number of preservice teachers</th>
<th>Number of in-service teachers</th>
<th>Participating schools</th>
<th>Precollege students impacted (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2012-2013</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>230</td>
</tr>
<tr>
<td>2</td>
<td>2013-2014</td>
<td>10</td>
<td>5</td>
<td>3</td>
<td>160</td>
</tr>
<tr>
<td>3</td>
<td>2014-2015</td>
<td>14</td>
<td>5</td>
<td>3</td>
<td>200</td>
</tr>
<tr>
<td>4</td>
<td>2015-2016</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>190</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>45</td>
<td>23*</td>
<td><strong>11</strong></td>
<td><strong>780</strong></td>
</tr>
</tbody>
</table>

* Three teachers participated in two cohorts.
** One school participated in three cohorts.

Preservice Teachers

- Preservice and in-service teachers were integrated by a common objective of improving science education. Through a summer academy, they designed, aligned and evaluated 20 teaching units. Preservice teachers helped the in-service teachers learn scientific techniques, including bacterial isolation and characterization, PCR, and electrophoresis. In-service teachers, in turn, helped the preservice teachers with teaching methodologies and communicated the difficulties that they may face in the teaching profession in terms of the facilities and infrastructure in the schools as well as other challenges.
- We developed community service activities, where our preservice teachers would impact other schools not directly participating in our program. The preservice teachers would select a teaching unit, based on the needs of a particular school and also offer workshops on research techniques. We impacted four schools through this program.
- Preservice teachers worked on scientific research projects on microbial ecology, including the isolation and characterization of bacteriophages, cellulase-producing bacteria, agarase-producing bacteria, and antibiotic resistance bacteria.
- Preservice teachers presented their results in various local and national symposia, such as the Puerto Rico Interdisciplinary Science Meeting and the American Society for Microbiology National Meeting.
In-service Teachers

- Transformation of the school curriculum.
  - Participating teachers added a research component to their class syllabi.
  - Participating teachers have adopted at least six of our teaching units and manuals as part of their curriculum, and are actively using them.

Precollege Students

- We had an increase in the number of students who applied to the science programs at UPR Cayey from the Benjamin Harrison High School, one of our participating schools.
- A total of 18 students were mentored for their scientific fair projects. Each one won at the regional level and three won at the state level and represented Puerto Rico at the International INTEL fair.
- Improvements in student performance in the sciences was evidenced by the results in the Puerto Rico standardized test at one of the schools.

Institutionalization

- Initiation of the institutionalization of incorporating research experiences to the science teacher preparation program.
- The assessment instruments used for the practicum site visits now include items for the evaluation of research activities in the classroom.
- Improvement of the research infrastructure for undergraduates at UPRC
  - Renovation of a microbial ecology and science teaching lab for research and science teaching support.
  - New equipment, including thermocyclers, nanodrop instrument, and a gel documentation system.
1. The Research Team Model for Undergraduate Research was proven to be effective. In this model, all constituents (faculty, graduate student, undergraduate student, and technician) are determinants in the advancement of individual research. Students identifying with other students, trying to accomplish similar goals, propels all of them cumulatively to reach higher standards. This model is centered on alternating roles between the mentor and those mentored within the team over time, independent of the rank or length of experience each member has in the laboratory.

- A total of 390 undergraduate and 71 graduate students participated in the five research teams: Tropical Ecology, Genomics, Extremophile Microbiology, Biomaterials and Agricultural Biotechnology, throughout the four years of the program.
- Before the HHMI research experience, 34% of the students in the research teams reported to have the goal of getting an MS, PhD or MD/PhD, after the experience, this number increased to 63%.
- 93% of the students say the HHMI experience motivated them to pursue graduate studies.
- 100% of the students identified the HHMI research experience as having helped prepare them for graduate school.
- 36 HHMI undergraduate and master’s student researchers entered graduate school as of year 4 of the grant.
  - 13 entered the master’s program at UPR-M.
  - 19 entered PhD programs in US institutions.
  - 2 entered an MD/PhD program in US.
  - 2 entered a Post Bac program.

2. Twenty-eight U.S. Junior Scientists (JS) visited UPR-M throughout the four years of the program to interact with the students through workshops, collaboration in host research labs and diverse social activities. By immersion into an almost exclusive Hispanic population, the JS reported increased awareness of experiences and perspectives shared largely by minority students. They reported that by understanding these differences, they will be better at mentoring and therefore retaining minorities in US graduate programs. JS also became aware of the intellectual capacities and high motivation of the UPR-M students and learned about the students' language, social barriers and priorities.

They learned about the collaborative Research Team model, of the quality, training and dedication of students, and furthermore, they identified common and unique challenges that underrepresented minorities (URMs) face and how this should inform mentoring strategies. Furthermore, JS commented on how the visit motivated them to get involved in URM activities in the US and how the experience enhanced their professional development. A total of 396 students participated in the workshops offered by the visiting scientist. Students reported gaining research knowledge on new tools and techniques, as well as developing research skills and awareness of graduate studies.

3. First- and second-year students were enticed into research-related activities through the research technique workshops, Student Research Opportunity webpage, and the undergraduate research symposium. A total of 189 freshman/sophomore students participated in the general research workshops. All participants agreed they learned about a research tool and that the workshop motivated them to search for other research experiences. This activity represented the first research workshop experience for 93% of the participants. Of the 197 undergraduate students who presented orally at the annual undergraduate research symposium throughout the years of the program, 96% agreed the symposium experience was positive. Among the 1,946 students registered in the Student Research Opportunity (SRO) homepage as of February 2017, 97% agreed the SRO homepage encouraged them to pursue research opportunities and 95% plan to use the web page in the future.
The grant sought to develop the medical and scientific research leaders of tomorrow, and promote STEM diversity, undergraduate education must remove the barriers that discourage persistence, impede retention, and prevent the success of underrepresented students. At the same time, an increasingly complex world requires new curricular models that prepare undergraduates to face some of our most daunting global challenges and a future we cannot yet envision. At the University of Richmond, we will do both through a comprehensive plan called URISE: University of Richmond Integrated Science Experience.

- A central goal of our program was to increase numbers of traditionally underrepresented students graduating with STEM degrees. At the beginning of our grant in 2012, 3.6% of STEM graduates at Richmond were underrepresented ethnic minorities (Black or African American, Hispanic or Latino/a, American Indian or Alaska Native, and Native Hawaiian or other Pacific Islander); in 2016, 15.8% of STEM graduates were from these groups, a more than four-fold increase. In the same time period, we saw a 32% increase in first generation STEM graduates.

- Successful curricular models to prepare undergraduates included:
  - The URISE Summer Bridge Program that has helped students build science and math skills and an inclusive community through civic engagement science projects and mentored research. Of the 55 students (15-20 per summer) who have participated in the summer bridge URISE program (all students from groups traditionally underserved in STEM), 100% have persisted in STEM beyond the first year (taking additional STEM courses after completing IQS or SMART in their first year), and all of them have conducted summer research after their first year and 66% are continuing research in the summer after 2nd or 3rd year. Among the first URISE cohort, 93% have declared STEM majors; 79% of the second cohort have declared STEM majors (another 16% are STEM related majors and STEM minors, e.g., Healthcare and Society or Environmental Studies). All of the third cohort enrolled in at least two STEM courses in the fall 2016. The university is in the process of raising endowment funds for the URISE program and this coming summer we will expand the experience to two cohorts of 15 students.
  - The Integrated Quantitative Science (IQS) first-year interdisciplinary (biology, chemistry, physics, calculus, computer science) course was revised from our previous grant. The excellent student outcomes, including building of research skills through course-based research and development of strong quantitative and interdisciplinary competencies, were also documented through a variety of assessment measures. This course has been described in two earlier publications (CBE Life Sciences¹ and JCST²) and was featured in the journal Nature³ as a model for undergraduate education training for the next generation of scientific researchers. Of students who enrolled in the new version of IQS, 86% completed the two-semester course series and 99% of students completing IQS took additional STEM courses (more overall courses as well as a larger variety of STEM courses). Of the students who have completed IQS, 92% who have declared majors are in STEM and 100% of those students have graduated with STEM degrees in four years.
  - The Science, Math, and Research Training (SMART) first-year interdisciplinary (biology, chemistry, calculus) was designed, like IQS, as a theme-based active learning course with course-based research projects. The learning community model in this case was developed to include students who did not have access to training in high school that would position them for immediate success. For the SMART course, 100% of students have finished the 2-semester course, 87% have conducted summer research, 1 Caudill L et al. 2010. Impact of interdisciplinary undergraduate research in mathematics and biology on the development of a new course integrating five STEM disciplines. CBE—Life Sci Edu 9:212-216.
and these students (nearly all from traditionally underserved groups) have reported high self-efficacy in STEM and engagement in their work. Almost all (98%) of SMART students are taking additional STEM courses and 95% who have declared majors are STEM majors (80%) or minors. A variety of assessment measures such as SALG, CURE, and EDAT showed increases in core competencies and scientific skills as well as metacognitive and engagement gains. Faculty from several institutions have worked with Richmond HHMI faculty to develop similar course models at their institutions.

- We have made significant progress toward “institutionalizing” our HHMI funded programs where assessment evidence documented ongoing success. The efforts to facilitate long term commitment have come from the faculty working in the URISE program with support of the offices of the dean, provost, president and board of trustees. Assessment data supporting the success of students, particularly those traditionally underrepresented in STEM, convinced stakeholders to invest time, funds, and energy into institutionalizing the programs. Major accomplishments include:

  - Hiring and authorizing the hiring of five additional faculty lines (one each in biology, chemistry, computer science, mathematics and physics). Each of these lines has commitments to teaching in the IQS, SMART and Integrated Science minor courses. These lines are also expected to contribute to offering undergraduate research opportunities to students from these programs. One of the lines (in Biology) includes in the teaching load, the directorship of the URISE summer bridge program. These hires will not only let us sustain, but also to expand our efforts in inclusivity in STEM.

  - Hiring on permanent university lines two postbac positions for working with URISE, SMART and IQS. The HHMI-funded postbac program demonstrated that we could mentor our own graduates from groups traditionally underserved in STEM to play roles in peer teaching/mentoring in the URISE Program while also conducting mentored research with faculty. Our HHMI-funded postbacs obtained graduate positions in excellent Ph.D. programs or science positions at research institutes.

  - Creating a faculty leadership role and a new program called “Integrated and Inclusive Science.” This program encompasses URISE, SMART, IQS, the Integrated Science minor and the new cross school, co-curricular Science Leadership Scholars Program (http://jepson.richmond.edu/major-minor/science-leadership-scholars-program.html), which were all goals of our grant. The program and faculty director will also oversee summer research experiences for URISE, SMART and IQS students as well as development of new courses and programs and a new faculty learning community on inclusive pedagogy.

  - Hiring a permanent administrative coordinator who will help collect and analyze ongoing assessment data as well as help administer these programs and newly created interdisciplinary science/math programs and courses.

  - Raising an endowment (The Richmond Guarantee) that can fund students who finish IQS and SMART the summer after the first year. Subsequent summers can also be funded for these students through another endowment (A&S Student Research Fund). This process is ongoing, but is already supporting former IQS and SMART students who are conducting research in their second, and third summers.

  - Plans and funds for renovation of classrooms and laboratories to create a new integrated science suite where interdisciplinary courses will be taught in state of the art collaborative spaces.
In 2015, the University of Texas- Pan American (UTPA) transitioned to the University of Texas Rio Grande Valley when the two legacy institutions, UTPA and the University of Texas at Brownsville were consolidated. Faculty, staff, fellows and students contributed their insight to help us accomplish our overarching goal: ‘to increase the number of Hispanics who pursue a graduate education in Science research subsequently increasing the number of highly educated underrepresented individuals in the scientific work force.’ Our work was divided into four main areas. Major accomplishments under each objective include:

Objective 1: Develop the new two-year HHMI Leaders in Scientific Research Program that will promote interdisciplinary scientific inquiry, develop a student’s leadership skills, and prepare students for graduate school

- A total of 78 fellows (94% Hispanic) were supported by the program in 6 cohorts exceeding our expectations of supporting 60 students. A total of 35 (91% Hispanic) fellows have graduated, of which 80% were in a 2-year (i.e., fellowship lasting 2 years) cohort model, compared to 20% in a 1-year cohort model.
- Of the 35, 16 (46%) matriculated to graduate school with 10 (28%) of them still intending to matriculate, but delayed mainly due to financial constraints. This compares well to (1) the HHMI 2001-2010 cohorts in which 33% (N=58, of which 68% were Hispanic and 100% in a 1-year cohort model) of the fellows matriculated to graduate school and (2) a USDA Hispanic Serving Institution grant funded series of cohorts running at UTPA/UTRGV since 2003 in which 55% (N=80, percent Hispanic unknown) matriculated to graduate school.
- Fellows from the various cohorts participated in weekly data presentation meetings covering a wide variety of STEM disciplines, including biology, chemistry, physics, agroecology, mathematics, computer science, civil and mechanical engineering, and psychology, ensuring that students were exposed broadly, thus fostering a multidisciplinary community. Data presentation meetings also served a social function to bring the community together, along with giving students an opportunity to practice their presentation and critiquing skills.
- Fourteen (14) peer-reviewed publications were co-authored by students in the cohorts.
- Thirty-five (35) research presentations were given by fellows at national conferences.
- Three (3) graduate research assistants were supported, two of whom are graduated and are working in positions that make use of the skills learned during their assistantship. One of them is our Assistant Director for the UTRGV Office of Engaged Scholarship and Learning and the other is a Research Assistant doing program assessment at our Center for Excellence in STEM Education.
- Undergraduate student survey showed that lack of motivation to study and pursue STEM disciplines was NOT a significant factor for our students leaving STEM. The focus of “building the pipeline” was re-centered around barriers to learning soft skills, such as building professional networks, improving presentation skills, financial concerns and perceptions about familial barriers. Faculty from a variety of STEM (biology, chemistry, mechanical engineering) along with non-STEM disciplines (communication, political science, and marketing) worked together for these professional development trainings.

Objective 2: Develop new scientific curriculum that prepares a larger number of students for science research careers.

- A guided inquiry activity to test the issues that would arise from switching from our currently practiced traditional ‘cookbook’ approach was implemented with test sections (those that did the inquiry lab) and control sections (those that did the traditional ‘cookbook’ approach) such that the effect of the student instructors was factored out. The hypothesis being tested was that we would see gains (measured with pre and post-tests) in student (1) content knowledge, and (2) confidence in answering questions. A total of 218 students participated in the study. It was found that there was no significant difference (p 0.5) in student content knowledge or confidence as a result of the inquiry lab, but there was a significant difference (p 0.5)
in confidence between pre- and post-tests indicating that any kind of experiential learning improved confidence.

• A research/inquiry-based curriculum Faculty Learning Community was established to identify barriers to implementing these activities into the classroom. A course-based research content expert from the UT Austin Freshman Research Initiative gave a workshop to members of the community which included potential solutions to the perceived barriers. Six faculty across biology and chemistry have designed diverse inquiry activities and are implementing them with a view to becoming resources for other faculty who want to make the switch thus assuring that lessons learned are passed on in the community.

Objective 3: Increase the pipeline of “high potential” Hispanic high school students that pursue a career in a science discipline.

• Thirty (30) high school fellows did research internships at UTRGV. All that have graduated matriculated to college, three at UTRGV.
  • The program was an excellent bridge to college as all students reported that the internship relieved many of their anxieties surrounding the transition to college and were now feeling confident in and looking forward to ‘going away’ to college.
  • Six new Science Activity Modules (SAMs) for high school students, (three in chemistry and three in physics) were developed in collaboration with area science teachers to increase the repertoire of UTRGV Mobile Laboratory (originally funded by a grant from HHMI) activities and to supplement under-resourced local school districts.

• Fifty-seven (57) teachers received professional development training from the Mobile Laboratory Coordinator on the theory and practical use of the SAMs in Teacher Training Opportunity (T-TOP) workshops. This has increased the visibility of the Mobile Lab and UTRGV to area school districts and teachers and answers the call by local school superintendents for more UTRGV community engagement.

• The effectiveness and community awareness of the Mobile Laboratory Program was highlighted in a 2015 survey across the freshman chemistry classes (N=258, who come from a 4,000 square mile area and including Hidalgo, Cameron, Willacy and Starr counties). Among the UTRGV student respondents, 27% recognized the Mobile Lab, with 95% of the students who had participated in its activities saying that it ‘influenced them to pursue science careers’.

Other:

• Establishment of a student/mentor research community and support software called HIVE.edu to facilitate everyday activities of the community. Data that is collected in this community is relational and temporal connecting assessment with activity data on an individual basis allowing faculty the granularity to chart the progress of each student.

• The HHMI grant efforts were coordinated across campus with non-STEM-oriented offices such as Community Engagement Office, Engaged Scholarship and Learning, HESTEC (Hispanic Engineering, Science and Technology Week), Learning Assistance Center, Center for Excellence in STEM Education, U-Teach, and Center for Teaching Excellence.
The objective of the grant was to establish the Center for Science and the Common Good (CSCG) to help science majors consider the responsibilities that come with scientific leadership, understand the ethical, political, and religious context in which science operates, be able to explain science to the public, and include members of underrepresented groups.

Established an interdisciplinary Center for Science and the Common Good

We established the interdisciplinary CSCG, which incorporates coursework and internships designed for students to explore the intersection of science and society, a speaker series exploring how scientists influence and engage with society, and a research immersion program for students underserved in the sciences. Three CSCG courses were developed with support from HHMI in departments that did not previously have science-related courses. The new courses include Science and the Common Good and Global Health, in the politics and international relations department and, Decoding Science, in the media and communication studies department. These courses are offered each year and are available to students from all majors. The speaker series brings in ten speakers per year, including some panels of speakers, who give a presentation on campus and have smaller discussions with groups of students about their careers and how they bridge science and the common good. During presentations by individual speakers from 2013-2015, an average of 145 undergraduates attended the sessions and completed surveys. The most highly attended talks included two talks representing different views on causes of defects in frog development by David Kelly and Tyrone Hayes. In surveys, students remarked on the differences in the speakers’ data and presentation styles. People across campus and from our local community are welcome to attend the seminar series. Our FUTURE research program is designed to bring students from populations underserved in the sciences into our research community during the summer before they matriculate in college or following their first year at Ursinus. During four years of support from the HHMI grant, 33 FUTURE Students who were first generation college students, members of underrepresented minority groups, women in science, or students with disabilities participated in the program. All of these programs will be maintained through funding from the college and through the endowed bequest of approximately $1.5 million.

Strong participation of underserved students in the sciences.

We found that the CSCG Fellows program and the FUTURE Summer Research program had a strong participation rate of students from underrepresented minority (URM) backgrounds related to the percentage of underrepresented minority students pursuing STEM majors on our campus. During the time frame of the HHMI grant, the percentage of URM students pursuing majors in science has increased steadily from 9.9% to 14.6% and the average proportion of URM students among STEM majors over the past five years is 12.3%. Among CSCG Fellows, 12% (7 of 57) during the first four years of the grant are URM students, which represents 12% of the CSCG Fellows. There are always more applicants to the CSCG Fellows program than can be accepted and these data show that this selective process does not result in a decreased participation rate of underrepresented minority students who are science majors. We found even stronger participation of URM students in the FUTURE Summer Research Program, which is designed for students from underserved backgrounds in the science. During the grant, 16 URM students out of the 66 FUTURE students and their undergraduate FUTURE mentors participated in the program, representing 24% of participants. This percentage is twice as high as the percentage of URM students who participate in our STEM programs. The FUTURE summer research program correlated with an increased rate of persistence of URM students in STEM majors. All students who participated in FUTURE planned to major in science and were URM students, first generation college students, women in science, and/or students with disabilities. While 57% of STEM majors persisted to graduation across campus for the entering class of 2012, 94% of FUTURE students persisted to graduation in STEM. URM students in the 2012 entering class completed STEM majors at a rate of 46%, 11% lower than the rate for the entire cohort. However, URM students in the FUTURE program completed STEM majors at a rate of 78%, 1.7 times higher than their URM peers and 1.4 times higher than all students in the 2012 cohort (Table 1). While there could be selection for motivated students to apply to the FUTURE program, this high success rate suggests that the program itself has a strong positive effect on student retention in the sciences and mathematics.
MAJOR ACCOMPLISHMENTS FOR NON-CAPSTONES

Professional development for faculty

Programming developed with HHMI funds had a positive effect on professional development of faculty members. Individuals participated in new activities and developed new programs. These included a workshop for faculty development, development of novel courses, development of skills in assessment, and bringing new students into the laboratory. Faculty members developed six new courses and revised three courses to include information on connections between science and society. These courses were taught by faculty members from five departments, including politics, media and communication studies, psychology, biology, and chemistry. A workshop was designed for faculty members to develop skills needed to teach communication of science to a broad audience. A total of 15 faculty members representing 7 majors participated. Four of them will integrate what they learned into the new CSCG courses and six will integrate techniques into the revised courses. Some descriptions of the influence of these professional development opportunities are included below (Table 2).

<table>
<thead>
<tr>
<th></th>
<th>% students beginning a science major</th>
<th>% students persisting as a science major</th>
</tr>
</thead>
<tbody>
<tr>
<td>All students entering the college in 2012</td>
<td>50% (228/456)</td>
<td>57% (129/228)</td>
</tr>
<tr>
<td>All FUTURE Student participants, 2012-16</td>
<td>100% (33/33)</td>
<td>94% (31/33)</td>
</tr>
<tr>
<td>URM students entering the college, Fall 2012</td>
<td>11% (24/228)</td>
<td>46% (11/24)</td>
</tr>
<tr>
<td>URM FUTURE Student participants, 2012-16</td>
<td>55% (18/33)</td>
<td>89% (16/18)</td>
</tr>
<tr>
<td>Non-URM students entering the college, Fall 2012</td>
<td>89% (204/228)</td>
<td>58% (119/204)</td>
</tr>
<tr>
<td>Non-URM FUTURE Student participants, 2012-16</td>
<td>45% (15/33)</td>
<td>100% (15/15)</td>
</tr>
</tbody>
</table>

Table 1: Persistence of FUTURE Students in science majors. These data compare all students, URM students, and non-URM students who were either 1) part of the college class entering in fall 2012 that was scheduled to graduate in 2016 or 2) FUTURE Students between 2012 and 2016.

Workshop on Communicating Science: A workshop on communicating science was developed after faculty indicated that they would benefit from practice in teaching communicating science to a broad audience. This workshop was attended by 15 faculty members representing the biology, chemistry, computer science, media and communication studies, philosophy, politics, and psychology.

CSCG Courses: A faculty member in our Politics Department developed and taught a global health course. She wrote about this professional development opportunity: “I loved teaching global health. It gave me an opportunity to do some research into a new area, and I learned a lot (including how much more I have to learn). The students were some of the best I’ve ever had and the CSCG cohort really raised the bar. They were curious, hardworking, smart and fun. They liked and supported one another, so the atmosphere in the class was great. It was a real pleasure!”

Assessment: The faculty member who coordinated assessment for the grant indicated that this helped her develop skills in assessment that will be useful in aiding assessment for the campus as a member of the Outcomes Assessment Committee. She particularly benefitted from the relationship she developed with our off-campus assessment consultant for the grant.

Young research students: A faculty member in our neuroscience major wrote: “FUTURE showed me how immensely valuable early immersion in meaningful research experiences can be for underrepresented students. Because of this program, I feel very confident inviting at-risk students into my research lab as early as the summer prior to their sophomore year. I plan to continue this practice for the remainder of my career.”

Table 2: Selection of faculty members’ reflections on professional development opportunities
The grant’s objective was to prepare majors for success as future leaders in science and medicine, and to prepare non-majors to be scientifically curious and literate leaders in society, regardless of their eventual career emphasis.

**Aim 1. Enhance and expand our two-year HHMI Fellows research program and include an emphasis on leadership in STEM.**

The STEM research culture has been changed at W&L because of our HHMI program. Our two-year HHMI Fellows program began in 2008 with eight students, initially open to bioscience students and expanded to all STEM disciplines in 2012—it now recruits ten students per year. The program includes a research preparation course, and a two-year intensive research experience, with supply funds, and funds to present research at a national meeting. A total of 72 students have benefited directly from this program; 70 completed the two-year research experience; and all but two of our graduates are in graduate or medical school programs. During the last three years, fellows have presented their data at 30 national meetings, are working with mentors on publications (26 papers in preparation, submitted or published), and nine grants were submitted based on HHMI-funded work done by these and former HHMI Fellows.1 An example: [http://blogs.biomedcentral.com/bmcseriesblog/2017/03/21/cob-web-spiders-wrap-prey-diverse-silk-proteins-expanding-silk-applications/](http://blogs.biomedcentral.com/bmcseriesblog/2017/03/21/cob-web-spiders-wrap-prey-diverse-silk-proteins-expanding-silk-applications/). In addition, 13 of the current 20 fellows have been engaged in peer mentoring of other beginning students in their research labs. Two years ago, fellows instituted their own mentoring program where second-year fellows mentor incoming first-year fellows. It’s a between-lab program so it also builds community as well as supporting the new research students. The fellows program (funded by W&L) will continue in its current form, emphasizing leadership and community building in STEM.

The program’s success has had an impact on the number of students doing summer and multi-term research in bioscience and all of STEM. For example, in 2008, when the HHMI Fellows program began, there were three bioscience students who had an extended research experience (two or more years) similar to that proposed for HHMI Fellows. In 2017, 27 bioscience students are involved in an extended research experience not funded by HHMI. This is in addition to 20 W&L-HHMI Fellows per year in various STEM fields, including the biosciences. Non-bioscience STEM departments are only just beginning to collect data on multi-term research experiences not funded by HHMI, but we expect a similar, although delayed trend, in all of STEM. Since 2009, student academic year research with STEM faculty has increased by over 250% (from 80 in 2009-10 to 206 in 2015-16). STEM summer research with faculty has also increased significantly (43 in 2009 to 79 in 2016). Our online summer research application process has been adopted for all STEM summer research applications and that has promoted increased advertising of research opportunities to all. Students now come to W&L asking about early research opportunities and with the expectation of doing research for an extended period. Demand is likely to continue to increase due to our efforts to encourage students to consider the large variety of research options available across STEM. W&L was able to accommodate this large expansion of student research due to (1) faculty hires funded by the previous HHMI grant and by W&L; (2) increased grant funding to individual faculty members; and (3) increased W&L summer research funding.

**Aim 2. Create the Integrative and Quantitative (IQ) Center to provide a centrally located, technologically rich interactive space for our student-faculty community for teaching and research.**

This space idea blossomed from STEM faculty discussions during year 1 of HHMI grant 1 (2008) and became a reality through HHMI and W&L funding in 2012. The ground floor of the science library was completely renovated and opened in September 2013, bringing together flexible learning spaces with state of the art instrumentation and computational power for data visualization. View the IQ Center website for more details on the instrumentation and resources available within the space: [www.wlu.edu/iq-center](http://www.wlu.edu/iq-center). The IQ Center focuses on active learning, so prior to IQ Center opening, HHMI-funded workshops served to introduce undergraduate faculty members to innovative student-centered learning pedagogies, IQ Center flexible teaching spaces, and IQ Center technologies, hardware and software. Participants were unanimous.
MAJOR ACCOMPLISHMENTS FOR NON-CAPSTONES

in their enthusiasm for such training sessions, so we expanded use of the IQ Center to all who wished to incorporate science and technology into their teaching and research, irrespective of discipline. That year was amazingly productive as students and faculty members across campus learned about the space and its capabilities. Once the Center opened and during that first year alone, 52 faculty members from 25 departments and programs across the undergraduate campus used the IQ Center to teach modules in 42 courses. Thus, 926 students from all STEM disciplines, as well as from a few courses in humanities and arts, utilized the Center’s technologies and innovative teaching spaces. Feedback from faculty and students was so positive that we were motivated to continue to offer these and similar workshops, the majority of which are now funded by W&L. In addition, as new technologies are added to the center, we run workshops to instruct faculty members about them. Both faculty members and students have been excited to use this space for coursework and research. Center tours, workshops, individual tutoring and special programs for faculty members have inspired design of new courses/modules that utilize active learning approaches in addition to one or more space features and equipment. Faculty report that both formative and summative assessments suggest that students find the course material more engaging and learning gains equal to if not better than in the past. W&L has institutionalized the position of the center coordinator, initially funded with the HHMI grant.

Aim 3. Use the IQ Center for faculty training in new pedagogy and research methodology.

During one week in fall and winter, faculty academies occur and we have designed some of these on STEM pedagogy, and IQ Center technology, hardware and software. Working groups (ideally 8-12 participants) enhanced interactions between participants, and these faculty academies (24 thus far) have been an excellent tool for encouraging faculty members to incorporate what they have learned into their teaching and/or research. In addition, and on request, the Center accommodates special programs and one-on-one instruction in whole classes, faculty, students and faculty/student research teams (79 thus far) that focus on one particular tool to be used for teaching and/or research. As a result, more courses and modules have been developed that highlight applications of STEM. More investigative experiences and/or research-centered courses are available to majors in STEM as well as non-majors who must take three science and math courses (one of which must be a lab course). All are well-subscribed by our students and have been a good recruiting tool for students interested in research. In addition, students who do not choose to participate in an intensive research experience are exposed to research in their course work that will eventually be published (see above blog link). In addition, faculty have developed new modules in their courses to take advantage of the technologies and flexible learning spaces in the IQ Center. Since the IQ Center was completed (fall 2013), students in 104 STEM courses and 35 non-STEM courses have benefited from this new learning environment and technologies. Thus our workshops and programs within the IQ Center have already impacted student learning not only in STEM but in the arts and humanities at W&L.

W&L now supports innovative STEM pedagogy projects, active learning STEM faculty cohorts and a component of the college strategic plan focuses on the future of STEM pedagogy at W&L. Within this STEM initiative, three main areas of concentration have emerged: more widespread adoption of active learning pedagogies, the recruitment and retention of a diverse student body, and an increased commitment to interdisciplinarity.

Aim 4. Provide extracurricular opportunities for students to develop STEM leadership potential.

In addition to those opportunities reported in Specific Aim 1, STEM students work in the IQ Center, help recruit the next cohort of research students, tutor beginning students in introductory STEM classes, mentor incoming first-year students in our five-week summer Advanced Research Cohort (ARC) program, and help program activities for ARC students. None of these kinds of opportunities were available prior to our HHMI funding so we have nothing to compare this to, but we do know that there is a greater sense of community within STEM because of it.
Whittier College’s HHMI grant was intended to “advance talented college students into math and science teaching careers, and enable a set of Whittier Union High School District science and math teachers to make curricular innovations as they work with Whittier College’s diverse faculty and student teaching and research fellows.” Our major activities included establishing pairs of practicing high school teachers and college STEM students, and asking them to prepare and implement lessons in high school classes. A key feature was a workshop held each summer in which the high school teachers, college students, and Whittier College faculty came together to address questions about research and teaching, and to develop specific activities and lesson plans. We believe that the following represent our major accomplishments:

- Over 100 lesson plans or activities have been created for use in high school STEM classes. The vast majority of these have been delivered by Whittier College students working directly with their paired high school teachers. The working relationships between the teachers and student fellows were largely positive.1 Another measure of success is that high school teachers continue to use most of the lessons and activities developed.
- A total of 9 in-service high school teachers and 19 undergraduate STEM majors participated in grant activities.
- Whittier College graduates approximately 50 STEM majors each year. Before the grant, it was rare for a STEM major to directly enter our credential program (we estimate 2 in ten years). Since the beginning of the grant, 7 Whittier College STEM students have entered the teaching profession, or are currently enrolled in credentialing programs.
- Three manuscripts are in review or preparation.
- Five conference presentations have been made based on research associated with the grant.
- Thus far, 6 practitioner presentations have been made by participating high school teachers, most at annual meetings of the California Science Teachers Association or California Mathematics Council.
- Multiple high school teachers have moved into positions of leadership within their districts, at least in part because of work associated with the grant. District structures support dissemination, through co-planning and shared curricular activities. Two biology teachers, one math teacher, one environmental science teacher, and one physics teacher have all held “Lead Teacher” positions within the district. Some of the activities developed have now been adopted for use across all schools within a district.
- Each Whittier College student participant has presented research results at minimally one local conference, and some have presented posters at national conferences, such as the annual meeting of the Society for Neuroscience.
- Fieldwork components embedded with Whittier College Education Department programs will be enhanced based on the successes of this grant.
- An unintended result (given our focus on high school teaching) is that at least 4 of the 19 Whittier College student participants have become interested in teaching at the College level. Each of these students is now pursuing, or will apply to, graduate programs.
- The Education Department at Whittier College, in large part because of the efforts of Lauren Swanson, one of our major grant leaders, has become more intimately integrated with mainstream STEM teaching at Whittier College. A Freshman Writing Seminar course based on STEM learning has been offered by Dr. Swanson, and a paired team-taught series of courses in Neurobiology and Perspectives on Science Education is now a regular feature in our curriculum. These courses provide opportunities for STEM majors to explore science education within formal coursework, an opportunity that has not previously existed on our campus. Thus far, about 100 Whittier College students have taken such courses, which means that this number of STEM students, who would most likely never have experienced any educational coursework, have now been exposed to education as a discipline.

• As a part of the above-mentioned Neurobiology/Education paired courses, 48 students have prepared and presented activities to the elementary students at the Broadoaks School, a teacher preparation model school housed on the Whittier College campus.

• Whittier College student participants uniformly reported that having “authentic” classroom experiences (co-planning, implementation, and reflection) help them determine whether or not teaching is a viable career option for them.

• Whittier College student participants uniformly reported a heightened respect for the teaching profession, even they do not decide to pursue such a career.

• A total of 12 Whittier College faculty members have been involved with grant activities. In each case, faculty members have become more aware of the challenges and opportunities inherent in high school teaching. In some cases (those faculty members who have been more involved in grant activities), direct and ongoing collaborations have resulted between college and high school teachers. In other cases, Whittier College faculty members have become engaged in education research.

• The good relationships that already existed between Whittier College and the particular high schools involved have improved to include collaboration within STEM programs.
**Highlights of the 2012 Mini-grants**

During their orientation meeting, program directors of 2012 grants were offered the opportunity to apply for collaborative mini-grants that would synergize their similar objectives and strategies. Three mini-grants were awarded.

**Quantitative Biology Mini-grant**

**Lead Program Director, Paul Overvoorde, Professor of Biology, Associate Dean of the Faculty, Interim Dean, Macalester College**

One group of six institutions (Macalester, Bryn Mawr, Oberlin, St. Olaf, Lewis and Clark, and the Claremont Colleges; Figure 1), Q6, with grants that included programs to improve students’ quantitative skills set about first to conduct an exhaustive search for an existing instrument that would help describe the quantitative skills of incoming science students. Finding none, they then worked as an interdisciplinary team to create a cross-institutional survey that focuses on life-science students and reflects the skills indicated in national reports such as Bio2010, Scientific Foundations for Future Physicians, and Vision and Change, as being vital for success in increasingly quantitative fields. The collaborative included educational psychologists and statisticians at University of Minnesota and Iowa State University.

---

*Figure 1. Institutional Members of Q6*
The survey, BioSQuaRE or the biology science quantitative reasoning exam, https://www.macalester.edu/hhmi/biosquare/, emerged from an iterative process and focuses on skills in data visualization, algebra and functions, statistics, modeling, and probability. Based on psychometric analysis of the response data from over 1,000 students at twelve post-secondary institutions, there are multiple lines of evidence for the validity of inferences made using the instrument. The blueprints for the instrument were derived from multiple national reports and faculty members confirmed the importance of the skills and competencies we set out to assess. In addition, the items are internally consistent, display a range of difficulty, and at both the model-level and item-level, student response data fit the Rasch model. A manuscript describing the tool’s properties is currently under review. The collective is currently carrying out a study to examine the potential connection of student performance on the instrument with high school preparation, as well as persistence and performance in subsequent biology course work.

Over a dozen presentations on the development of the tool have been shared at national and international meetings. The BioSQuaRE is freely available through an instructor survey on the group’s website. Instructors or departments using the instrument receive a report that provides aggregate feedback about their student responses and how these compare to the growing database of responses.

**CRE Mini-grant**

**Lead Program Director, Catherine Mader, Professor of Physics, Hope College**

A collaborative of seven grantees, comprising Gettysburg, Gonzaga, Hope, Smith, and Tougaloo Colleges, and North Carolina Central and Tuskegee Universities, were awarded the second mini-grant.

The goals of the Collaboration were to advance the implementation of institutional CRE projects at seven different institutions through:

- developing local expertise to translate research topics into viable CREs by
  - identification of exemplary CRE curricula
  - professional development of faculty, instructional staff, and learning assistants
  - identification and implementation of CRE assessment programs
- sharing ideas and CRE products

The Collaboration facilitated the creation of new CRE models through shared professional development activities. There were two workshops attended by over 30 CRE developers working on over 35 CRE model development projects. The workshop provided the opportunity to discuss both common assessment efforts (CURE/RISC), that would allow the Collaboration to work together to identify the impact of their different models on student self-reported benefits, and other forms of assessment that were appropriate for the institutional setting of the CRE offering. To date, 39 CRE models developed by Collaboration institutions have been posted on the CUREnet website.

The Collaboration leadership team was challenged to develop a common understanding of what is meant by a course-based research experience. This was challenging since members of the team were implementing CREs in a diverse group of institutions, for a wide range of student populations and in different disciplines. In the end, we reached consensus that the key elements to a course-based research experience are shown as spokes on a wheel in
Figure 2 (from Staub, 2016). We felt that all six elements were key to the success of a CRE, but the exact way in which each CRE implements these elements varies based on institutional context and student audience. Three of the elements provide motivation to carry out the work and make the experience more authentic:

- the **context** for the research project.
- the opportunity to **discover** the answer to questions that no one else has answered before.
- **ownership** of elements of the research process from posing questions to developing procedures to analyzing data.

In addition, like all traditional research, three other elements must be present:

- research must lead to reliable and reproducible results, so **iteration** is necessary.
- researchers must learn the language of their field in order to **communicate** clearly and effectively with their research community.
- research findings really have no value if they aren’t **presented** to the broader community.

Exactly how these elements are incorporated in a specific CRE model depends upon institutional context. See the framework for determining how to incorporate these elements in a new CRE.

The Collaboration also pooled CURE Survey data from 42 CRE course offerings to explore if it was possible to discern which elements in our CRE models had the greatest impact on student self-reported gains in various aspects related to the nature of research, skills and abilities needed to do research and professional development as a researcher. We determined that all CRE models that engaged students in research throughout the entire course, rather than simply incorporating a short research module within a more traditional laboratory course led to gains that significantly exceed the national averages for learning gains self-reported by students engaged in apprentice model research experiences. When we clustered CRE models based on similar course elements, we found that those that shared elements that indicated they were high in “novelty” and “student design” had the greatest gains.

---

1 Staub N et al. 2016. Course-based science research promotes learning in diverse students at diverse institutions. CUR Quarterly 37: 36-46.
Competency-based Curriculum Development

Lead Program Director: Timothy Ward, Professor of Chemistry, Berry Family Chair in Science, Millsaps College

The Millsaps Xavier mini-grant was based on the following overarching competency: *Students should demonstrate both knowledge of and ability to use basic principles of mathematics and statistics, physics, chemistry, biochemistry, and biology needed for the application of the sciences to human health and disease.* This competency covers the important components on competencies E1-E4 of the AAMC-HHMI SFFP report (2009).

Upon initial discussions, we realized that attempting to plan and implement our project on all eight HHMI-AAMC competencies would be over-ambitious and very likely unachievable. We therefore decided to select the most important concepts from E1-E4 and express these in a form of ‘overarching competency’ stated above.

The major accomplishments of this partnership included:

- Faculty from both institutions further developing their abilities as educators particularly in competency-based teaching in collaborative workshops.
- Developing a rubric for assessing identified scientific competency components during a competency assessment workshop led by David Hanauer, Indiana University of Pennsylvania.
- Collaboratively developing active learning and cooperative techniques to enhance student reasoning and application skills.
- Strengthening of the faculty capacity for competency-based education at both institutions.

Curricular outputs and assessment of the E2-E4-based overarching competency included:

**Millsaps**

- In order to assess the students’ understanding of experimental design components, we used assessment tools consisting of a description of an experiment followed by questions about the experiment. In the first set we asked students to identify various components of the experiment. In the second set, we asked students not only to identify components but also to indicate how an experiment (in which there was only one experimental unit per treatment) could be improved. All students were able to articulate a hypothesis for the experiments and most were able to identify the independent and dependent variables and to describe the concept of replication, but only 50% were able to state the null hypothesis. Regarding the improvement of an experiment, 56% were able to identify the problem with the design and suggest an improvement.
- Presentation of data was assessed on individually-written lab reports of team-designed experiments. The nature of the experiments differed somewhat from semester, but students were generally successful in presenting their data appropriately, with an average score of 90% on their reports.
  - The breakdown for the design components were
    - Articulate hypothesis – 97%.
    - Identify null hypothesis – 50%.
    - Identify dependent variable – 59%.
    - Identify independent variable – 56%.
• Describe the concept of replication – 74%
• Identify a problem with the design and suggest an improvement – 56%

Xavier

About 80-85% of students performed well (scored at least 70% on a quiz or a test and performed correctly, the tasks/skills tested on the practical portion of the exam where the understanding is based both on the skill and the written explanation of the unexpected results) in General Biology and Foundations of Biology lab.

Sixty percent of students performed well (scored at least 70% on a quiz or a test and analyzed correctly their own data or the data from a research article) in Foundations of Biology lab when tested on basic understanding of what the data showed. In contrast, 80% did well using the above criteria when tested on the same component (understanding and analyzing data) in the Genetics lab.

Thirty-five percent of students did not score 70% or higher (did not meet minimum standards) in Foundations of Biology lab when tested on connecting the data including those from control groups to the hypothesis being tested and determining whether the data supported the hypothesis. Using the same criteria, about 45% did not score 70% or higher how when tested on the same component (connecting the data including those from control groups to the hypothesis being tested and determining whether the data supported the hypothesis) in Genetics lab.
**Components of Persistence Programs**

The 2012 Capstones website includes a matrix of elements the grantees (Figure 1) developed to improve persistence of their students in science.

![Components of Persistence Programs at Capstone Institutions](https://d32ogoqmya1dw8.cloudfront.net/images/liberalarts/components_persistence_programs_cap_v3_324.jpg)

The 2012 non-Capstones grantees submitted a matrix based on the one on the Capstones website (Figure 2).

![Components of Persistence Programs at Non-capstone Institutions](https://d32ogoqmya1dw8.cloudfront.net/images/liberalarts/components_persistence_programs_cap_v3_324.jpg)
Lessons Learned

HHMI encouraged the 2012 College Grantees to share freely their major lessons. These advice below represents the opinions of program directors with 5 to 30 years of experience in undergraduate science education reform. As you consider their recommendations, please keep in mind your own institutional context.

Programmatic

- Get firm commitments from faculty and other key stakeholders before the grant begins. For example, negotiate course releases for program administration prior to grant start. Recruit staff from relevant offices such as those from admissions or multicultural affairs.

- Institutionalization of grant programs takes substantial time and effort, especially in the current fiscal climate, where there is high turnover of upper administration. As early as the first grant year, begin planning to sustain programs and engaging key stakeholders. Early discussions may include potential faculty and staff lines, curricular and space support, and coordination with key offices such as student housing or academic skills center.

- Have a Plan B. What is the alternative plan if the proposed strategy encounters a roadblock? For example, what will you do if you are unable to fill the postdoc position that’s critical to curriculum development and assessment? What is the plan in case of unscheduled faculty sabbaticals or departures? What is the alternative if a national trend negatively affects your recruitment of participants, such as national decreases in teacher recruitment? Plans B may sometimes lead to serendipity.

- Effective translation of the successes of HHMI-funded programs to other institutions requires a system for directly educating chairs, deans, presidents, and trustees about the importance of supporting innovative teaching approaches that elevate undergraduate education.

- Although course-based research experiences (CREs) have the potential to produce a paradigm-shift in the way that an institution educates its students, there is a great degree of variability in institutional support for faculty who wish to take on the risk of piloting CREs. Further, there is very little incentive from tenure and promotion committees to reward such innovation. Rather than trying to innovate in every grant area possible, focus grant programs on those aligned with institutional priorities for sustainable impact.

Faculty

- Faculty buy-in is the key to success and communication and flexibility are keys to faculty buy-in. Be persistent and pervasive in recruitment of faculty. For example, enlist a broad coalition of participants across relevant departments during the proposal planning process. They may later serve as ambassadors to help recruit more faculty in their respective departments. Ensure that your faculty development structure accommodates both early and late “adopters.”

- Remind faculty that student research is a win for them as much as students. For example, immersion in summer research allows faculty and students to confront serious challenges in their full ambiguity and may result in preliminary data for research grant applications. Students are so tuned into technology that they can serve as a major resource to faculty in areas of data science.
• Involving incoming faculty in grant activities such as assessment is a way to shape their teaching practices early, which is easier than converting those existing faculty members who are resistant to change.

• Faculty development needs to be ongoing throughout the grant term to accommodate subsequent expansion of new pedagogical practices into other courses and faculty recruited later in the grant term. Remember that there is usually a lag between faculty embrace of curricular change in theory and in practice. Be persistent at “peeling away layers of habit and past training.” And be inclusive of contingent faculty in development opportunities.

**Students**

• Programs for inclusion and persistence in STEM must last beyond the first undergraduate year. Students may persist through their comprehensive first-year programming only to encounter obstacles in courses lacking in active-learning pedagogy and academic support prevalent in their first year. Consider revision of second-year biology courses and in some sections of organic chemistry, as well as inclusive pedagogy training for faculty.

• Older peers are competent at mentoring their juniors in the logistics of research and thus can be of great assistance to faculty mentors. Create a peer tutoring program with a “virtuous cycle,” wherein participants in the tutoring sessions served as a recruitment pool for the next cycle of tutors.

• Competitive financial compensation is a key to retaining under-resourced students so that they may immerse themselves in research without concerns about job earnings.

• It is important to include “soft” skills such as team work in the training of future scientists. Colleagues in other departments may be able to help in this way by giving workshops in leadership and conflict management to students.

• Participating in outreach with science majors has a major positive impact on preservice teacher’s perception of teaching science. On the other hand, science majors may be intrigued by the possibility of teaching but also may not have the time to devote to true teacher activities like making lesson plans. Science teacher preparation is most effective and long lasting when shared between science and education departments.

**Administration**

• Negotiate any necessary policy changes with institutional administrators before the grant begins. Don’t assume that the institution can adapt rapidly to the needs of the grant. For example, is there any potential conflict between remuneration for student research and the institution’s financial aid policy?

• If you have an administrative structure in which one person is in charge of each initiative, remember to include opportunities for communication across initiatives.

• Obtain commitments for interdisciplinary efforts at the departmental levels to ensure that there is coverage for the efforts in addition to faculty disciplinary responsibilities.

**Assessment**

• Assess the existing infrastructure to assess the grant. In some cases, an external consultant can be very helpful. Be sure to have enough personnel capacity for real time analysis of data for formative assessment. Develop detailed assessment plans with colleagues for each initiative before the grant begins.
• Be comprehensive in the approach to assessment. One possible model is a three-pronged approach: (1) collect basic data to demonstrate that the grant’s objectives are being met; (2) collect data longitudinally to place the program experience in a longer-term perspective; and (3) analyze data with the perspective that assessment is “most valuable when it inspires conversations and reflections among faculty.” Remember that qualitative assessment may allow reveal learning outcomes not apparent from quantitative assessment.

• Expect assessment to be a learning process. Many grantees begin with a wide array of assessment tools and through formative assessment drill down to the tools that provide the most valuable info with the least student survey fatigue.

Cross-institutional collaboration

• Curricular collaborations will be most successful when the institutions are aligned in terms of programmatic goals, faculty expertise and interest, and preparation of the student bodies. Geographic proximity is a lesser factor in collaborative success. “The best collaborations between or within institutions are driven by real shared issues or questions and not geography.”

• Collaborations need continuity to survive changes in institutional or grant leadership and personnel, e.g., a program director shared across the institutions.

• Remember to keep track of and learn about your collaborative process in addition to producing collaborative outcomes so that you will have a potential model for future partnerships.

• Effective activities and lessons will be more widely adopted within a school district than at unrelated schools. Word of mouth is effective within a school district with effective means of communication, but having participants in leadership positions within the district helped as well.

• Be willing to adapt your program to the priorities of community leaders, when possible, in partnerships that involve geographically isolated underrepresented populations.
**Agenda for The 2017 Synthesis Meeting**

In April 2017, the entire 2012 grantee cohort met to discuss the big issues that these program directors thought were facing undergraduate science education at PUIs. The conversation was informed by the lessons learned through their grants.

**HHMI Headquarters**
Chevy Chase, Maryland
April 18-20, 2017

**Co-Chairs:**
Deloris Alexander, Tuskegee University
Gregory Davis, Bryn Mawr College
Kathleen Siwicki, Swarthmore College
Kimberly Tanner, San Francisco State University

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00–4:00p</td>
<td>Arrival and Check-in</td>
<td>Conference Center</td>
</tr>
<tr>
<td>5:30–6:00p</td>
<td>Reception</td>
<td>Great Hall</td>
</tr>
<tr>
<td>6:00–7:00p</td>
<td>Dinner</td>
<td>Dining Room</td>
</tr>
<tr>
<td>7:00–7:30p</td>
<td>Welcome &amp; Meeting Overview</td>
<td>Auditorium</td>
</tr>
<tr>
<td>7:30–9:30p</td>
<td>Session I: Celebrating Successes and Sharing Strategies</td>
<td>Atrium</td>
</tr>
<tr>
<td>9:30–11:00p</td>
<td>Social</td>
<td>The Pilot</td>
</tr>
</tbody>
</table>

**Tuesday | April 18**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:30–8:15a</td>
<td>Breakfast</td>
<td>Dining Room</td>
</tr>
<tr>
<td>8:30–9:30a</td>
<td>Session II-A: Improving Access, Inclusion, Persistence in STEM</td>
<td>Conference Room D124/125</td>
</tr>
<tr>
<td></td>
<td>Carolyn Sandoval, Instructional Consultant, Texas A &amp; M University, Center for Teaching Excellence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bryan Dewsbury, Assistant Professor, University of Rhode Island, Department of Biology</td>
<td></td>
</tr>
<tr>
<td>9:30–9:45a</td>
<td>Break</td>
<td>Great Hall</td>
</tr>
<tr>
<td>9:45–11:45a</td>
<td>Session II-B: Improving Access, Inclusion, Persistence in STEM</td>
<td>Conference Room D124/125</td>
</tr>
<tr>
<td></td>
<td>Small group discussions and activities focused on themes related to improving access, inclusion and persistence.</td>
<td></td>
</tr>
<tr>
<td>11:45a–12:30p</td>
<td>Group Photo</td>
<td>TBD</td>
</tr>
<tr>
<td>12:30–1:15p</td>
<td>Lunch</td>
<td>Dining Room</td>
</tr>
<tr>
<td>1:30–3:00p</td>
<td>Session III-A: Creating Conditions for Faculty Adoption of Evidence-Based Teaching</td>
<td>Conference Room D124/125</td>
</tr>
<tr>
<td></td>
<td>Susan Shadle, Director, Boise State University, Center for Teaching and Learning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>This session will focus on barriers and drivers to change in STEM education. Our exploration will look at common issues that cross institutions and will prompt participants to think specifically about their institutional context. We will use this as the basis to explore ideas related to faculty stages of adoption and the selection of contextually-sensitive strategies aimed at change on our individual campuses.</td>
<td></td>
</tr>
</tbody>
</table>

**Wednesday | April 19**
<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>3:00–3:15p</td>
<td>Break</td>
<td>Great Hall</td>
</tr>
<tr>
<td>3:15–4:45p</td>
<td>Session III-B: Creating Conditions for Faculty Adoption of Evidence-Based Teaching (continues)</td>
<td>Conference Room D124/125</td>
</tr>
<tr>
<td>4:45–5:30p</td>
<td>Free Time</td>
<td></td>
</tr>
<tr>
<td>5:30–6:00p</td>
<td>Reception</td>
<td>Great Hall</td>
</tr>
<tr>
<td>6:00–6:50p</td>
<td>Dinner</td>
<td>Dining Room</td>
</tr>
<tr>
<td>7:00–8:30p</td>
<td>Session IV-A: Meeting Student Demand for Research Experiences</td>
<td>Conference Room D124/125</td>
</tr>
<tr>
<td></td>
<td>Malcolm Campbell, Professor and Director, Davidson College, Biology Department and Martin Genomics Program</td>
<td></td>
</tr>
<tr>
<td>8:30–9:15p</td>
<td>Session IV-B Meeting Student Demand for Research Experiences</td>
<td>Conference Room D124/125</td>
</tr>
<tr>
<td></td>
<td>Large group discussion in which we will share experiences attempting to meet student demand for research experiences at our institutions, including challenges, successful and unsuccessful strategies.</td>
<td></td>
</tr>
<tr>
<td>9:30–11:00p</td>
<td>Social</td>
<td>The Pilot</td>
</tr>
<tr>
<td>**Thursday</td>
<td>April 20**</td>
<td></td>
</tr>
<tr>
<td>7:30–8:15a</td>
<td>Breakfast (and Room Checkout)</td>
<td>Dining Room</td>
</tr>
<tr>
<td></td>
<td>(Please return your guest room key to the Conference Center.)</td>
<td></td>
</tr>
<tr>
<td>8:30–10:40a</td>
<td>Session V: Looking Forward Impromptu Poster Session</td>
<td>Conference Room D124/125</td>
</tr>
<tr>
<td></td>
<td>Three rounds of poster sessions during which all attendees will have an opportunity to present at least one idea, gained from Synthesis 2017, that they can implement as soon as they return to their home institutions (i.e. “What could I do tomorrow?”).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Round 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Round 2</td>
<td></td>
</tr>
<tr>
<td>10:40–11:00a</td>
<td>Break</td>
<td>Great Hall</td>
</tr>
<tr>
<td>11:00a–12:15p</td>
<td>Session V: Looking Forward Impromptu Poster Session (continues)</td>
<td>Conference Room D124/125</td>
</tr>
<tr>
<td></td>
<td>Round 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflections</td>
<td></td>
</tr>
<tr>
<td>12:30–1:15p</td>
<td>Lunch</td>
<td>Dining Room</td>
</tr>
<tr>
<td>1:30–2:00p</td>
<td>Closing remarks from HHMI</td>
<td>Auditorium</td>
</tr>
<tr>
<td>2:00p</td>
<td>Departures</td>
<td>Conference Center</td>
</tr>
</tbody>
</table>