Principles and Practices Fostering Inclusive Excellence: Lessons from the Howard Hughes Medical Institute's Capstone Institutions

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ABSTRACT

Best-practices pedagogy in science, technology, engineering, and mathematics (STEM) aims for inclusive excellence that fosters student persistence. This paper describes principles of inclusivity across 11 primarily undergraduate institutions designated as Capstone Awardees in Howard Hughes Medical Institute's (HHMI) 2012 competition. The Capstones represent a range of institutional missions, student profiles, and geographical locations. Each successfully directed activities toward persistence of STEM students, especially those from traditionally underrepresented groups, through a set of common elements: mentoring programs to build community; research experiences to strengthen scientific skill/identity; attention to quantitative skills; and outreach/bridge programs to broaden the student pool. This paper grounds these program elements in learning theory, emphasizing their essential principles with examples of how they were implemented within institutional contexts. We also describe common assessment approaches that in many cases informed programming and created traction for stakeholder buy-in. The lessons learned from our shared experiences in pursuit of inclusive excellence, including the resources housed on our companion website, can inform others' efforts to increase access to and persistence in STEM in higher education.

INTRODUCTION

Many students with strong interests in science, technology, engineering, and mathematics (STEM) leave these fields while in college (Seymour and Hewitt, 1997; President's Council of Advisors on Science and Technology, 2012). Disparities in STEM outcomes are fundamentally incompatible with democratic values of fairness and informed citizenry (American Association of Colleges and Universities, 2015) and fuel pressing practical problems, including a shortfall of STEM workers at a time of increasing demand for educated scientists and engineers (Carnevale *et al.*, 2011). Furthermore, solutions to today's scientific and societal challenges will benefit from a diversity of perspectives and talent (e.g., Hong and Page, 2004; Freeman and Huang, 2014). Yet the fastest-growing segment of our population, people of color, are least likely to

access quality STEM education and are most likely to leave STEM majors (Hoffer *et al.*, 2007; National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 2011).

This essay addresses these challenges by looking at programs to support students traditionally underrepresented in STEM (based on race/ethnicity, gender, socioeconomic and first-generation college student status, and/or having attended underresourced high schools) developed by 11 predominantly undergraduate institutions that are long-term recipients of funding from the Howard Hughes Medical Institute (HHMI). Recognizing the capacity of small colleges and universities to innovate, HHMI funded 47 such institutions in 2012 to develop program models that broaden participation in STEM and that could be replicated elsewhere. Of those 47, the 11 whose programs we describe here were designated as "Capstone Awardees" to recognize the maturity and success of their programming in undergraduate science education (HHMI, 2012).

The Capstone Awardee institutions ("Capstones") constitute a range of institutional missions, student profiles, available resources, and geographical locations (Table 1). Each Capstone worked locally to develop programs that fit its needs and institutional culture while building upon the published literature on effective practices in broadening participation. Despite the differences in context, there are striking similarities in the approaches they developed to support the persistence of students from groups traditionally underrepresented in STEM. The goal of this essay is to articulate the lessons and fundamental principles leading to success among these 11 programs so that others might find useful information that will help expand opportunities for inclusive excellence. At the Capstones, efforts to broaden participation were successful. As a group, these institutions have shown significant improvements in production of college graduates with science degrees, including increases in underrepresented minority students within recent decades (Table 2).

The Capstone group has also developed a website that complements this essay and provides the fine-grained detail necessary to support others interested in learning from these experiences. Readers are encouraged to visit the site, entitled Supporting STEM Success in a Liberal Arts Context (found at http://serc.carleton.edu/liberalarts/index.html). It demonstrates how theoretical frameworks and effective practices come together on the ground at institutions with distinct students, priorities, and constraints. With more than 60 pages of content, the website provides both detailed descriptions of the programming at each institution and a synthesis of lessons learned.

PROGRAM DESIGNS THAT SUPPORT STEM PERSISTENCE FOR ALL

Students persist in or leave STEM majors as a result of a confluence of reasons (Seymour and Hewitt, 1997). One core principle of all 11 programs described below is creating a web of support that is responsive to gaps in students' ability to take advantage of educational experiences and opportunities while nudging them into, rather than away from, STEM programs. Each of our colleges has customized this approach to its own environment. Common across all programs is the basic premise that the educational structure at an institution needs to serve

TABLE 1. Profiles of Capstone institutions[a]

Capstone institutions	City, State	Special characteristics	Undergraduate student population	Student-to-faculty ratio	Percent admitted 2014	Expenses per student	Endowment per FTE[b]	SAT Critical Reading 25th/75th percentiles[c]	SAT Math 25th/75th percentiles[c]	ACT Composite 25th/75th percentiles[d]
Barnard	New York, NY	Single-sex: women	2573	10:1	24	$43,454	$112,995	640/730	620/720	29/32
Bryn Mawr	Bryn Mawr, PA	Single-sex: women	1308	8:1	40	$56,872	$470,682	620/730	620/730	28/32
Carleton	Northfield, MN		2057	9:1	23	$53,020	$397,561	660/750	660/770	29/33
CUNY Hunter	New York, NY	4-year, public	16,879	11:1	35	$19,380	$5129	520/620	550/640	NR[e]
Grinnell	Grinnell, IA		1734	9:1	28	$56,312	$1,087,059	640/740	660/770	30/33
Hope	Holland, MI		3455	12:1	77	$22,185	$57,756	540/650	550/670	24/29
Morehouse	Atlanta, GA	Single-sex: men HBCU[f]	2109	12:1	84	$30,330	$62,579	440/550	430/550	18/23
Smith	Northampton, MA	Single-sex: women	2563	9:1	42	$55,326	$535,454	NR	NR	NR
Spelman	Atlanta, GA	Single-sex: women HBCU[f]	2135	10:1	54	$30,049	$151,543	470/570	450/550	20/23
Swarthmore	Swarthmore, PA		1542	8:1	17	$72,986	$1,207,638	670/760	670/770	30/34
Xavier University of Louisiana	New Orleans, LA	HBCU	2359	14:1	66	$30,000	$53,194	450/550	420/560	20/26

[a]U.S. Department of Education Institute of Education Sciences National Center for Education Statistics, NCES Homepage (http://nces.ed.gov().
[b]Endowment assets reported as of fiscal year 2014. FTE, full-time equivalent.
[c]SAT, Scholastic Aptitude Test.
[d]Admission scores reported for Fall 2015 entering class (https://nces.ed.gov/ipeds/datacenter/Default.aspx).
[e]NR, not reported.
[f]HBCU, historically black college or university.

TABLE 2. Changes in science graduates between the 5-year periods, 1994–1998 and 2011–2015

Institution	Percent increase in total grads	Increase in science grads overall	Percent increase in science grads overall	Increase in URM science grads only	Percent increase in URM science grads only
Barnard	44.2	128	16.5	58	41.7
Bryn Mawr	25.6	193	44.0	50	63.3
Carleton	15.7	311	36.2	117	78.5
CUNY Hunter	91.3	3230	123.6	711	39.9
Grinnell	45.0	280	52.9	76	69.7
Hope	52.3	346	34.8	56	72.7
Morehouse[a]	−21.7	−236	−30.4	−257	−50.3
Smith	18.8	281	28.9	121	62.7
Spelman	7.5	70	7.0	4	0.4
Swarthmore	29.8	298	48.0	132	75.0
Xavier University of Louisiana[b]	−17.6	−204	−15.5	−313	−31.9

Data from IPEDS for periods indicated. Science majors includes standard STEM fields, including pre–health preparation and some professional fields, such as nursing, science teacher education, but excluding technical certifications like "science technicians." Includes first and second majors in the 2011–2015 range, but they were not separately reported in 1994–1998. URM, underrepresented minority students including: black or African American, Hispanic or Latina(o), Native American or Alaska Native, Native Hawaiian or Pacific Islander (2011–2015), two or more races (2011–2015). Note that Morehouse, Spelman, and Xavier are HBCUs; nearly all their graduates for both periods fit into the URM category. The percent increase in total grads is based upon the number of baccalaureate graduates reported for the earlier and later periods. The increase in science grads overall is simply the difference in science majors granted for the two periods (combining changes for URM science grads with all other science grads). The percent increase in science grads is the percentage increase based upon the previous columns. The URM columns are parallel to the previous columns, except for URM only.
[a]During the first time period, enrollment at Morehouse was larger than the later time period.
[b]Significant and ongoing disruptions related to Hurricane Katrina in 2005 impacted Xavier's subsequent enrollments.

the needs of all of its students, especially those from groups traditionally underrepresented in STEM; this is in contrast to the concept that the students themselves need to be "fixed." This fundamental assumption underpins the programs we describe here, which aim to enhance the educational experiences and outcomes of targeted students while simultaneously improving the program offerings institution-wide. For example, Carleton's whole-student approach (Gross *et al.*, 2015) conceptualizes the engagement, capacity, and continuity framework (Jolly *et al.*, 2004), with engagement comprising two elements: drive to succeed and sense of belonging. These elements are viewed as critical components along with the institutional and programmatic supports for learning that provide continuity and build student capacity. At Carleton, the FOCUS (Focusing on Cultivating Scientists) program, which started in 2007, has been designed around this model with an emphasis on getting students connected and involved in STEM departments from their first terms on campus. This program is successful at supporting participating students to continue in STEM; ~85% of FOCUS participants graduated with STEM majors. Rates of Carleton's students of color in general graduating in STEM have increased more than twice the amount of the increase for its students overall (increase of 78.5% vs. 36.2%) over time (see Table 2). The FOCUS program appears at least part of the reason for this increase.

The resulting implementations to broaden access vary across individual academic contexts. As shown in Table 3, each Capstone's program contains multiple components informed by the current literature on inclusive excellence. In some cases, the programs are discrete, and components are directed toward specific groups of students (defined cohorts or defined demographic and/or academic groups); in other cases, they are programs that encompass the breadth of opportunities available to all students at the institution. The variety

evident in the programs described here is a strength; each institution has designed and implemented programs that work in its own context.

Four program elements were particularly prevalent across Capstone institutions, indicating the ability of these elements to address fundamental needs in multiple contexts. These elements are cohort and mentoring programs to build community; research and inquiry-based experiences that strengthen scientific skills and identity; attention to quantitative skills as a common barrier; and outreach programs that broaden the pool of future scientists by solidifying undergraduates' disciplinary engagement and expertise. Although the Capstones have these elements in common, the individual programs look different, target different students, and fit into respective campuses differently at each institution. Their adoption by many of these institutions suggests their importance, but because of variations in institutional context, the outcomes are not directly comparable. Below we describe each common element and highlight institutional examples of its success. More detail on each implementation and its relationship to the institutional context is on the website.

Each of the common elements for fostering persistence is consistent with constructivist learning theories. In each of these theories (Tinto, 1987, 1997; Brown *et al.*, 1989; Lave and Wenger, 1991; Wenger, 1998), student learning is constructed through social relationships that bring students together around contextualized and authentic domain problems. Tinto's (1987, 1997) work on student participation and retention in higher education finds that persistence is most likely when students work in learning communities and classrooms that build bridges between the academic and interpersonal domains, helping to solidify students' sense of belonging to the academic enterprise and the broader life of the institution. The common elements of the Capstones' persistence programming share a number of features that are identified as effective by these learning theories.

TABLE 3. Components of persistence programs at Capstone institutions, sorted by frequency of adoption

Program component	Barnard	Bryn Mawr	Carleton	Grinnell	Hope	CUNY Hunter	Morehouse	Smith	Spelman	Swarthmore	Xavier of LA	Percent of institutions
Curricular innovations	X	X	X	X	X	X	X	X	X	X	X	100
Student research—Summer	X	X	X	X	X	X	X	X	X	X	X	100
Faculty development	X	X	X	X	X	X	X	X	X	X	X	100
Interdisciplinary program	X	X	X	X	X	X	X	X	X		X	91
Mentoring (faculty)	X	X	X	X	X	X	X	X	X	X	X	91
Mentoring (peer)	X	X	X	X	X		X	X	X	X	X	82
Cohort programs	X	X	X	X	X		X	X	X		X	82
Course-embedded research	X		X	X	X	X	X	X	X		X	82
Campus jobs	X	X	X	X	X	X		X	X	X	X	82
Inquiry-based learning	X	X	X	X	X	X	X	X	X	X	X	82
Student research—academic year	X	X		X	X	X		X	X		X	73
Career development	X	X	X	X	X			X	X		X	73
Physical space	X	X	X	X	X		X	X	X		X	73
Community outreach	X	X			X	X	X	X	X	X		64
Summer bridge	X	X	X	X	X	X	X			X	X	64
Developing quantitative skills	X	X	X	X	X	X	X	X				64
Community building					X		X	X	X	X	X	55
High school student Summer programs			X	X	X	X			X		X	45
Academic civic engagement	X	X	X		X	X						36
Technology (blended learning)	X	X	X			X		X			X	36

For each element discussed below, we highlight relevant aspects of these theories.

Build Community through Cohort and Mentoring Programs

Many STEM cohort programs are national models, providing inspiration for persistence programs for college students (Maton *et al.*, 2000; Barr and Matsui, 2008; Mellon Mays Undergraduate Fellowship, 2015; Posse Foundation, 2015). The success of these programs and a number of constructivist learning theories support the notion that learning happens because of and through social relationships (Tinto, 1987, 1997; Lave and Wenger, 1991; Wenger, 1998). Lave and Wenger (1991), for example, describe the importance of communities of practice to learning; these communities draw students together based on similar interests, foster relationships within the group, and help to socialize members into the shared practices and knowledge of the group. These processes advance student expertise in the domain of interest and create a sense of belonging to the group.

In STEM, this sense of belonging and engagement in relation to a community of practice is critical. Persistence requires students to envision themselves as part of a broader community of STEM practitioners. This can be particularly challenging on smaller campuses, where the population of students from a particular demographic or other group might be small, such that when students attempt to find their places in the context of their major departments or research groups, they may feel especially isolated. Many of the Capstone institutions recognize the importance of community building and social relationships. On nine of our campuses, we have specific programs that we designate as cohort programs. Students may join programs for a summer, an academic year, or their entire undergraduate careers. A detailed comparison of the components of the cohort programs is shown in Table 4, and detailed descriptions of the individual programs are available through the Capstone website.

Most of these Capstone programs include community building and mentoring by both peers and faculty members. Peer-mentoring programs include help with course work and the development of strategies for academic success. For example, the Science Associates are a diverse group of peer mentors at Swarthmore who engage introductory biology students in collaborative problem solving outside the classroom. Since the program began in 2005, the rate of persistence of underrepresented minority students as biology majors or minors has increased to the same level as that of majority students (Kudish *et al.*, 2016). Faculty mentors are typically drawn from academic advisers, cohort program advisers, research supervisors, or course instructors. Smith College's Achieving Excellence in Mathematics, Engineering, and Science (AEMES) Scholars program provides a cohort of incoming first-generation and/or underrepresented minority women opportunities for peer mentoring and faculty-mentored research during their first 2 years of college. The AEMES Scholars show significantly higher rates of persistence in science, participation in natural sciences advanced research, and gateway life sciences course grade point averages (GPAs; dissolving the GPA gap that previously existed between underrepresented/first-generation and majority students) relative to baseline before program launch in 2007 (cf., Katz *et al.*, personal communication).

TABLE 4. Characteristics of cohort programs at Capstone institutions that have them[a]

Institution	Program name	Summer bridge	Recruitment/selection	Research opportunities	Curricular component	Mentored by	Size of cohort (students/year)	Funded by	Peer mentoring
Bryn Mawr	STEM Posse	X	With Posse Foundation, before first year	X		Faculty	10	HHMI and college	
Carleton	FOCUS		With Admissions, before first year	X	X	Faculty	16	HHMI, NSF, and college	X
Carleton	Summer Science Fellows		Students apply in first or sophomore year	X	X	Faculty	4–5	HHMI, NSF, and college	X
Grinnell	Grinnell Science Project	X	Students are invited before first year	X	X	Faculty and staff	Up to 50	NSF, HHMI, Lilly Foundation, and college	X
Hope	Day1: Research Communities	X	Students are invited before first year	X	X	Faculty and staff	Four Day1 programs have capacity of 20 students Other program open to all first-year students	The Herbert H. and Grace A. Dow Foundation and college	X
Hunter	Hunter Summer Research Interns		Students apply	X		Faculty	6 every 2 years	HHMI	
Hunter	Hunter/HHMI Undergraduate Scholars		Students apply	X		Faculty and staff	6	HHMI	
Morehouse	HHMI Undergraduate Research Program	X	Students apply during sophomore year	X	X	Faculty and staff	7 per year	HHMI	
Smith	STEM Posse	X	With Posse Foundation, before first year	X		Faculty	10	College	X
Smith	AEMES Scholars		With Admissions and Mentoring Committee, before first year	X	X	Faculty and staff	20	HHMI, Dreyfus Foundation, Hearst Foundation, Janet McKinley Fund of Smith College, and college	X
Spelman	SMART		Students apply	X	X	Faculty	7	HHMI	
Xavier	BUILD Scholar Program		Students apply	X	X	Faculty	BUILD first and second years: 100 BUILD Trainees and Scholars:18–20	NIH	
Xavier	LS-LAMP		Students recommended to a committee during sophomore through senior year	X		Faculty	8–10	NSF	
Xavier	MARC and RISE		Students apply	X	X	Faculty	RISE: 12 MARC: 10	NIH	

[a]More details can be found on the Capstone website.

Many Capstones also provide support services that help students adapt to their campus cultures. In addition to support structures like learning centers, cohort programs, special problem-solving seminars, and peer-mentoring programs, more than half of the Capstones provide a Summer bridge program for incoming students (Table 3). For example, students participating in the 5-week Summer Scholars Program at Swarthmore develop a familiarity with the institution's academic expectations and benefit from the unique opportunity to get to know some of their professors before Fall classes begin. All faculty who work in the program continue to support students during their time at Swarthmore, in both formal and informal settings. Summer scholars are each matched to a faculty member and receive mentoring for the duration of their college careers.

All of the Capstone cohort or mentoring programs have components of cultural acclimation that help incoming students feel welcome and connected to their new campuses, their peers, and the STEM disciplines. Activities also include familiarization with support resources (learning or advising centers, tutors, and peer mentors), and some programs build community within a learning cohort or give students an early start on academic planning or involvement in a research project. In addition to support for introductory-level students, some Capstone programs at Carleton, Swarthmore, Spelman, Smith, and others extend mentoring beyond the first year, sometimes to support second-year students specifically, and at times lasting throughout a student's undergraduate years. For example, Grinnell has launched a program including a second-year science student retreat that has improved rates of success of targeted populations of students in gateway biology and chemistry courses (Gregg-Jolly *et al.*, 2016).

Develop Student Skills and Identity through STEM Research and Inquiry Experiences

Students are more likely to persist in STEM when they experience content-rich, meaningful, and connected research and active-learning pedagogies (Lopatto, 2010). According to constructivist learning theories, it is essential to create situated-learning opportunities (Lave and Wenger, 1991) embedded within authentic and contextualized domains of practice (Brown *et al.*, 1989) for effective learning to occur. The Capstones offer these experiences for students through undergraduate research apprenticeships, course-based research experiences (CREs), and inquiry-driven and interdisciplinary curricula, all of which typically provide students with opportunities to present their work publicly, both on campus and at scientific meetings.

Successful models for undergraduate research are described regularly in the Council on Undergraduate Research's *CUR Quarterly*, and the benefits of undergraduate research are well known (e.g., Hunter *et al.*, 2007; Russell *et al.*, 2007; Boyd and Wesemann, 2009; Lopatto, 2010). In the foreword to Lopatto's book *Science in Solution* (2010), Sheila Tobias, a leading advocate for the transformation of science education to increase accessibility, posits "an undergraduate research experience could be the cross-class leveler we've been searching for; one that provides the first-generation college student with some of the critical and self-critical habits of mind that more privileged young men and women bring with themselves to college."

Capstone research experiences largely follow an apprenticeship model, with all 11 offering summer research opportunities for undergraduates and eight offering a dedicated research experience for students from underrepresented groups during the academic year (see Table 3 as well as the *Developing Inquiry Skills* section of the Capstone website). This research apprenticeship model provides an example of Brown *et al.*'s (1989) concept of cognitive apprenticeship in which students learn to use cognitive tools through a process of teacher or expert modeling and explication of tacit understandings in an authentic domain. In STEM, strong mentoring, student participation in (or understanding of) a complete scientific investigation, connections between research and course work, and a more general understanding of the nature of collaborative research are key to the success of an apprenticeship research experience.

Student demand for dedicated research experiences often exceeds capacity at our small institutions. Some Capstones partner with research institutions to provide opportunities for their undergraduates. For example, City University of New York (CUNY) Hunter students might work in summer internships at the Marine Biological Laboratories in Woods Hole or at the Cold Spring Harbor Laboratories. Almost all of the students who participated in this program went on to pursue PhD or MD degrees. Emphasizing the importance of the relationship between a research student and her mentor, Spelman has run a Summer Visiting Research Fellows Program in which students work with African-American women scientists at research-intensive institutions and national labs.

Embedding authentic research experiences in courses not only expands the number of students who can participate but also improves the quality of science education for all (Laursen *et al.*, 2010; Shaffer *et al.*, 2010). CURE and SURE surveys reveal that students in research-like science courses report learning gains that resemble those reported by students in dedicated research experiences (Lopatto, 2010). CREs have been implemented at nine of 11 of Capstone institutions (Table 3). At Smith, faculty developed CREs in introductory-level courses to accommodate overwhelming student interest in research. These courses have yielded notable outcomes, including significant student self-reported learning gains and meaningful scholarly outputs for faculty and students (e.g., more than 20 student poster presentations at scientific meetings). In the Spelman biology department, integrating research into the curriculum nearly doubled the percentage of biology students who graduate with authentic research experiences. The program's success motivated widespread institutional reform: Spelman now has an undergraduate research Capstone program, and all Spelman students have a research experience.

In some cases, the focus of introductory courses has shifted to research with a focus on long-term investigation aimed at generating new knowledge, such as in the HHMI SEA Phages (HHMI, 2015) curriculum at Hope, Xavier, and others; Grinnell's Introduction to Biological Inquiry courses (Lindgren, 2010); and Smith's yearlong interdisciplinary courses for first-year students. Many other courses involve more piecework skill development, such as problem solving, use of the primary scientific literature, and writing and communicating in professional formats (poster presentations, grant applications, or scientific journal articles). Hope College emphasizes the group-work aspect of CREs, in which students view themselves as part

of a research learning community. Capstones offer course-embedded research experiences at all levels of the curriculum, sometimes linking skills and experiences between courses. For example, Barnard College has implemented a creative functional genomics curriculum focusing on the tobacco hornworm *Manduca* that spans every level of the curriculum, from introductory biology through five upper-level laboratory courses and into yearlong senior thesis projects (e.g., Koenig *et al.*, 2015).

Some would argue interdisciplinary or integrative projects are the pinnacle of a research experience because of the need to apply methods and information from various fields to address a specific problem. Multiple examples of learning pathways and the institutional structures needed to foster integrative or interdisciplinary learning are described on the Capstone website (see Integrative Learning section) and by Ferrett *et al.* (2013). A successful example is Morehouse's Interdisciplinary Research Collaborations Course, which involves the integrative investigation of a current scientific issue (e.g., obesity and epigenetics) culminating in a research proposal.

Despite these successes, Capstones encountered trade-offs in efforts to integrate research skills with course content. As an illustrative example, when Morehouse first offered courses newly designed to increase students' engagement in research, they found institutional requirements and lack of flexibility made enrollment difficult for students. This challenge led to revisions of the biology curriculum that permitted more student flexibility in course choices, allowing students to count research or biology-relevant course work from another department toward their biology majors. Now students can pursue their interests better and even craft an interdisciplinary STEM major.

Increase Student Success with Attention to Quantitative Skills

When limited opportunities for rigorous course work in quantitative skills—or lack of confidence with these skills—are impediments to student success and persistence, extra support for development and practice with these skills is critical. The use and development of quantitative skills are infused throughout the curricula at the Capstones, with seven of 11 implementing programs explicitly to support persistence of students from groups traditionally underrepresented in STEM (Table 3). Approaches range from implementation of defined computational interdisciplinary programs dedicated to enhancing quantitative work in existing courses to requiring special activities to enhance student practice and performance. Many of these examples tie quantitative skills preparation to situated learning (Lave and Wenger, 1991) and authentic domains of practice (Brown *et al.*, 1989), practices well grounded in learning theory.

In some cases, Capstones recognize student needs early by supporting quantitative preparation and success in introductory science courses. At Xavier, administrative staff identify new students in need of additional math preparation. These students must pass a course focused on development of quantitative skills before registering for introductory-level chemistry or biology courses; students may complete it before matriculating. Bryn Mawr offers an opt-in course designed specifically for students who intend to major in STEM but need to bolster their quantitative skills. The course is team-taught by faculty from the various science departments, using discipline-specific examples to provide context for the math. Because faculty who teach introductory science courses also teach this course, students recognize that it provides a real advantage to those interested in pursuing science.

Online resources can provide the convenience of self-paced work, and technology can reduce the likelihood that under-preparation might delay progress into a science major. At Carleton, underrepresented students who also have lower math placement scores are invited to use an online tutoring and assessment program, Assessment and LEarning in Knowledge Spaces (ALEKS, 2015). The blended-learning program at Bryn Mawr has been designed in part to increase the number of students from underrepresented groups earning STEM degrees and Bryn Mawr's "just-in-time" approach to math fundamentals provides online coaching when needed for STEM course work. Faculty members using the blended approach report that it helps them to meet the needs of a diverse student population. Impressively, experimental blended biology, chemistry, and geology gateway courses exceeded goals of completion with merit, resulting in averages of 93.5% overall and, remarkably, 95.1% for low-income students in those courses. Because online activities provide different levels of support or challenge, according to individual students' needs, the student learning data helped faculty identify and reach out to students who need either extra support or challenge. The growth of Bryn Mawr's leadership in the field of blended learning in the liberal arts provides insight into the process of institutional change. Although Bryn Mawr was an early adopter of the Internet as a teaching resource, it was not until 2010, once leadership at the college made using technology in the classroom a priority, that the program took off. Change may be slow at times, but strong leadership can accelerate transitions and yield results above and beyond what might have been originally imagined.

As working with large data becomes more important in STEM fields, computational skills are an important part of quantitative literacy. Bioinformatics or biomathematics programs at Hunter and Smith demonstrate how these skills can be developed in the context of biological problem-solving, strengthening access to the content. Rich contextual development of quantitative skills is also available through Bryn Mawr's interdisciplinary minor in computational methods and within its sustainability cluster. An important element of all three programs is collaborative work, often on interdisciplinary problems, which supports learning (Felder, 1995) and enhances student perception of a welcoming climate on campus.

Broaden the Student Pool through Outreach Programs

Community outreach is another common element of Capstone programs, broadening the pool of future scientists while simultaneously solidifying undergraduate students' disciplinary knowledge and identity as scientists. Consistent with learning theories, outreach helps to build communities of practice that socialize students in ways that advance their participation in the domain of learning, beginning with legitimate peripheral participation (Lave and Wenger, 1991) that solidifies a sense of belonging and socializes students into the community and practices of science.

STEM outreach activities allow current students and faculty to engage community members, students, and K–12 science

teachers in scientific activities and curricula that foster curiosity in STEM disciplines. Summer outreach programs for high school students are offered by five of 11 Capstones, and seven Capstones engage in community outreach programs (Table 3), which often support development of K–12 student interest in science. Barnard's intercollegiate partnership with LaGuardia Community College (CUNY) has been particularly effective: more than 85% of 350 past participants have enrolled at 4-year institutions, the majority with STEM majors. In a randomly selected matched control group of science graduates who had not participated in the program, only 61% transferred to a baccalaureate-granting institution.

Outreach programs at Capstones do more than recruit and expose young students to authentic scientific experiences. For example, CUNY Hunter College has a partnership with the Manhattan Hunter Science High School in which they offer workshops for college credit and summer research opportunities with Hunter faculty, affording students an accelerated pathway to a biotechnology BA/MA degree. Smith College's Summer Science and Engineering Program for high school girls serves as a testing ground for developing investigative laboratories that are incorporated into the undergraduate curriculum and have been disseminated beyond Smith (Merritt *et al.*, 2008; Kirby *et al.*, 2016).

In addition to the target participants, undergraduates from the Capstones benefit from the experience of developing and executing outreach programs, thus providing a dual benefit to the institution. As illustrated by Hope's outreach program of high-quality inquiry-based STEM activities, students get to share their own excitement about STEM and be the experts, enhancing their ability to see themselves as STEM practitioners. Swarthmore's Science for Kids program is associated with a summer music camp for fifth through ninth graders. Evaluation of the program indicates that serving as counselors in this program is particularly beneficial for students who have less-developed interests in their majors, consolidating their science understanding in ways that can serve as a scaffold to more effective work in the laboratory.

Summary of Program Elements

Decisions that students make about whether to pursue STEM are based on their full life experiences, including their past academic training and the cultures in which they grew up. Although we present program elements independently, the holistic experience of an individual student is a critical determining factor in academic success. Students must be actively recruited and supported in STEM fields by a welcoming community that offers them opportunities to be mentored by faculty and other students. Research experiences and classes with engaged pedagogical practices are powerful components of Capstone programs that empower students while addressing the research agendas of STEM faculty. Providing pathways for students to successfully complete quantitative work is important. Mastery of work that is perceived as particularly challenging can be empowering and enhance student self-efficacy, factors that contribute to persistence in STEM fields. Each of these program elements illustrates the principles of successful learning environments, consistent with the tenets of constructivist learning theories (Tinto, 1987, 1997; Brown *et al.*, 1989; Lave and Wenger, 1991; Wenger, 1998).

The Capstone programs are mature and have changed over time. As described in the examples above and on the Capstone website, implementation of one program element can lead to the development of others, and curricular reform in one department may lead to institution-wide programs. Some elements explicitly developed to support students from underrepresented groups were found to serve all students well, whereas other elements were adopted as a best practice and then found to benefit students from underrepresented groups in particular.

INCLUSIVE EXCELLENCE THROUGH THOUGHTFUL ASSESSMENT

Building programs requires concerted effort over time. Our comparison of the histories of persistence efforts across the Capstones highlighted one key ingredient to program success: ongoing, formative, and thoughtful assessment. Assessment data often provided the linchpin that launched programming at Capstones, providing palpable evidence for what was until then an anecdotal sense from students and/or faculty that there was inequality in persistence and outcomes for students from underrepresented groups. At times, the initial push for assessment came from within a department or institution. For example, Grinnell's Science Project, begun in 1992, grew out of analyses finding that students of color, first-generation students, and other students from groups underrepresented in the sciences (e.g., women in physical and computational sciences) were at risk of poorer academic performance in introductory STEM courses and were less likely to persist in these majors. In other instances, initial assessment efforts to understand student persistence at Capstones were propelled by encouragement from outside the institution. A series entitled Symposia on Diversity in the Sciences, sponsored by HHMI and attended by 76 colleges and universities between 2005 and 2008 (Snibbe, 2007) charged attending institutions with analyzing key academic outcomes for their underrepresented minority students in STEM. These efforts created impetus for program development at a number of institutions, including Smith, Carleton, and Swarthmore.

Reflecting back on the many years of our collective persistence efforts, the Capstones agree that understanding the complexities of persistence for underrepresented students in STEM requires a collaborative and holistic approach tied to institutional values. Institutions can paint a complete picture of their students only by evaluating multiple sources of data that examine outcomes and perceptions of stakeholders from a variety of viewpoints. Well-developed programs often gather both qualitative (e.g., open-ended surveys, focus group responses, casual observations) and quantitative (e.g., graduation rates, GPAs) data in the short and long term not only to understand whether they have made gains in persistence but also to identify why this change is (or is not) occurring.

Here we share some common assessment principles from across the Capstone institutions and identify future directions for honing assessment strategies that will help all of us working to enhance persistence on our campuses. Further details about assessment strategies and principles and pathways to institutional change can be found on our website (see Pathways to Institutional Change as well as Sustaining, Systematizing, Institutionalizing in the Persistence section).

Start with Good Questions

As Walvoord (2010) and other experts in the field of educational assessment (Banta *et al.*, 2009) make clear, the best place to start an assessment process is to ask questions that allow stakeholders to identify and articulate their goals for student learning. Once important goals are articulated, it is possible to examine current outcomes across underrepresented groups on relevant measures.

The following questions were helpful at the beginning of the process of understanding persistence needs at the Capstones:

- What are our students' strengths and needs?
- How do we define student success? (see *Identify Appropriate Metrics* for further detail)
- How are our students from various groups performing on these measures? Are there differences for groups traditionally underrepresented in STEM?
- Where discrepancies between groups exist, which outcomes does our community think are the most important to target? In tandem, where is there interest and energy at our institution that might help propel change?
- What insight can our data provide about the barriers underrepresented students face? Are additional data (e.g., focus groups, student survey data) necessary to forge a path forward?

The answers to these questions helped to target persistence efforts in the areas that needed the most attention and that were best aligned with faculty and institutional values.

Identify Appropriate Metrics

Capstones used a number of metrics to benchmark persistence efforts, many of which focus on objective and well-accepted outcomes, such as persistence of students in STEM at various watershed moments in their educational trajectories. To address questions of inclusive excellence, Capstones typically compare outcomes of different demographic groups on relevant measures and closely examine any differential rates of success. There was broad consensus among us that persistence in science is relatively easy to assess this way, but it is also easy to assess badly, by using poorly chosen comparison groups or measures that inadequately capture the nuance of our students' academic and educational trajectories. In this section, we review the kinds of measures that the Capstones used to understand student persistence for underrepresented groups and recommend some future directions.

Measurement of Access and Persistence in STEM. Comparing outcomes across institutions can be problematic due to local variations in population definitions, program structures, and desired outcomes. Utilization of nationally collected data can ameliorate some of these challenges, especially when looking at the data broadly. The Integrated Postsecondary Education Data System (IPEDS) provides the opportunity to examine changes in numbers of STEM majors. As shown in Table 2, comparing the 5-year period of time corresponding to the earliest HHMI grants to the most recent 5-year period shows a substantial increase in the number of science baccalaureate graduates at Capstone institutions and, in particular, in the number of underrepresented minority students graduating with science majors (for a fuller description of the definitions used, see Table 2, note a). While the work done at these Capstone institutions has largely been local and not coordinated with other Capstones, and we have no data to show the impact of particular program elements summed across institutions, the overall changes are positive, substantial, and meet the goals of the programs as well as institutional priorities for inclusion and persistence.

All of the Capstones agree that inclusive excellence demands further assessment of student outcomes beyond their completion of a STEM major. As a group, we concur that it is essential to examine data measuring the quality of educational experience and opportunity across demographics. Common ways to understand whether all students have equal access to opportunity and are equally likely to achieve excellence include measuring academic performance through such metrics as gateway science course grades or overall GPA in a STEM major. Many of our programs also monitor underrepresented students' participation in opportunities that our faculty agree are hallmarks of high-quality science education, most notably meaningful research opportunities. Transcript analyses may be used to observe student trajectories across years (e.g., using gateway-course enrollment as a baseline for interest in STEM and then tracking additional course work). An alternative is to measure intent at the beginning of college and track students' intended majors from time of application through graduation.

Persistence efforts would also benefit from more nuanced measurement and understanding of the putative mechanisms related to long-term STEM persistence and success for underrepresented students. The development of frameworks for persistence (e.g., Graham *et al.*, 2013) will help with these efforts. As noted previously, scientific engagement and identity as well as intent to continue often predict STEM persistence and success. These may be better proximal variables to assess than our current measures of persistence, as they can be gathered in an ongoing and formative way (rather than waiting to see what major gets declared or whether a student enrolls in graduate school). Common measures of students' self-reported engagement and competencies related to research experiences, including their future aspirations, attitudes about science and collaboration, and self-assessed science skills as measured by the CURE and SURE surveys, can also help in this regard (Lopatto, 2010).

Programmatically, the Capstones focus on removing barriers to STEM participation for underrepresented groups of students, offering support as students pursue their academic passions. More careful analysis of groups of students who leave *versus* enter STEM provides another promising avenue for understanding persistence (Consortium for STEM Success, 2015). At Grinnell, an effort was made to examine this issue by comparing the number of students who indicated they wanted to major in STEM on their admissions applications with the number of students who graduated with majors in STEM. This effort could be extended to comparing numbers of students from different demographic groups to see whether there are at least equal odds of underrepresented students entering STEM as other fields. By studying student academic migration patterns and the reasons motivating them, we will have a richer sense of the barriers and entry points to STEM, allowing more targeted interventions that obviate or capitalize on factors related to students' educational and career trajectories.

Assessment as Impetus for Change

Thoughtful and ongoing assessment at the Capstones has been essential to continued institutional investment in and success of our persistence efforts. Assessment data have been critical to the process of launching initiatives, honing programming, and generating institutional points of pride related to inclusive excellence and student success. Empirical data often make the case to external funders that there is a problem to solve and, later, that targeted programming has been effective. Although faculty are sometimes not convinced of the utility and impact of data-gathering and assessment efforts, especially if mandated from above, the leaders of Capstone programs overwhelmingly agree that our programs would not have been launched and sustained successfully without clear data revealing problems of access and persistence particular to each institution.

CONCLUSIONS

This paper draws from the experiences of 11 institutions seeking to strengthen the ability of students of all backgrounds to persist and succeed in their STEM programs. Grounded in knowledge that each student's needs and pathway are unique and that institutions and programs must provide support for all aspects of students' growth, these programs involve a wide variety of program elements designed to address academic needs and to provide a nurturing community for students, increase their sense of belonging in STEM, and strengthen their motivation to persist. Each institution started with evidence of a challenge, put together an initial program, and then collected data to understand how things were changing on campus. In response to these data, as well as to emerging challenges and success, the programs evolved into their current forms. In some cases, program elements were radically changed or eliminated; in others, new pieces were added to fill gaps. The result is a rich tapestry of programs with overlapping common elements, each uniquely reflecting the institution and its culture, history, and resources but united in providing a web of support for students of all types.

These Capstone programs were designated as such by HHMI for their maturity. They have had time to evolve and grow. Underpinning these stories is work by faculty and administrators on each campus to weave the program into the fabric of the institution. Resources were required, and in these cases, the HHMI funding played a crucial role in the development and assessment of pilot programs that drew the interest of faculty and administrators. However, funding alone was not sufficient for success. It was necessary for individuals throughout the institution to share a common understanding of the importance of these initiatives and of their purpose and how they should be implemented. While individuals served as critical catalysts or played essential functions, each is the work of an institution.

These programs were developed at small, predominantly residential colleges. HHMI selected this environment as one in which campus-scale change is the least difficult to achieve. In addition, it is an environment that maximizes the opportunity to support students, as they live on campus. Even in this best of cases, progress has been hard-won. However, we suggest that many of the lessons we learned can be transported to other types of institutions, either to an institution as a whole or to departments or programs that are similar in scale to those of our colleges (Condon *et al.*, 2016), just as we learned from other types of institutions in our own program development. This essay summarizing Capstone experiences in STEM education reform and the associated website including detailed information for each of the Capstone programs were designed to inform others interested in STEM education reform and inclusive excellence about our experiences. The assessment strategies we describe to motivate and drive change are not scale dependent, nor is the concept of providing a web of support that different students can tap in different ways. Scaling up research and inquiry-based learning is the challenge of our time; the move from a handful of research students to a class of 30 or 100 is no different in a big or small school and provides ideas for those who must scale from hundreds to thousands. The strategies we have developed for collaborating with research universities or communities can be reciprocated by large schools reaching out to smaller institutions in their regions or extended to building collaborative networks of institutions of different types and sizes. Our nation's small colleges have unique attributes that can be brought together with those of our leading research universities to create better opportunities for students in both settings.

Perhaps the most important lesson learned by our programs is the most obvious. In striving to support diverse students at our institutions more effectively, we learned things that benefited all students. As we studied programs that were failing to serve diverse students, we learned about the challenges facing all students. As we strengthened pedagogy, built community, and improved mentoring and guidance for diverse students, we identified scalable elements that helped everyone. Thus, the work to improve education for struggling populations, so critical in its own right, served to strengthen each institution as a whole.

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