Growth of a Science Center: The Center for Science and Mathematics Education (CESAME) at Stony Brook University

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Abstract

This report describes the origin and development of CESAME (The Center for Science and Mathematics Education) at Stony Brook University. The analysis identifies key ingredients in areas of personnel, funding, organizational structures, educational priorities, collaboration, and institutionalization. After a discussion of relevant issues in American education, the report explores the Center's priorities, including: (1) Outreach offering educational and research experiences for school teachers and students; (2) Science and mathematics teaching, leadership, and professional development: (3) Programs providing Ph.D. and MAT degrees in science education; (4) Research opportunities, scholarships, fellowships and funding at all educational levels; (5) Support for faculty in the development of new curricula and courses; (6) Partnerships and networking within and beyond the university; (7) Research in science and mathematics education. Activities are evaluated and presented in ways that can be used as guidelines for replication. The report concludes with a discussion of critical success factors and the future of the organization.

Contents

1 CESAME: Origins and Early Development

This report describes and analyzes the history, mission, activities, and growth of The Center for Science and Mathematics Education (CESAME) at Stony Brook University. CESAME has brought the resources of a research university to schoolteachers and students, while also leading a renewal of science education within the university. The development of the Center has been organic and evolutionary, building on accomplishments and responding to new challenges and opportunities, over the course of more than 20 years. The Center's mission now includes outreach to area schools, in-service training for school teachers, research and support in teaching and learning within the university, providing research opportunities for undergraduates, and administering advanced degrees in science education,

This study provides a history of the Center, placing it in the context of American education and considering the challenges encountered. The results of international tests have brought to light the weaknesses of American teaching and learning and the challenges that the country faces. The study draws on 15 years of evaluation activities as well as numerous other reports and documents. The program evaluations were based upon surveys, interviews, group discussions, observations, statistical measures, and analysis. These evaluation activities have resulted in reports analyzing most of the projects and activities undertaken at the Center. As we describe and explain the programs we will identify the critical success factors and point to broad lessons for American education.

The demands to improve education in the Unites States have become more insistent in recent years, particularly in the areas of science and technology. The responses to these demands have identified a range of priorities: more rigorous research on best practices in teaching and learning; raising the standards in student testing; including hands-on and applied approaches to science at all levels; increasing the use of technologies; and learning from the practices and experiences of other countries. These and other ideas and practices have been promoted, and some have begun to bear fruit. But some of the efforts have included typically American faults, most notably: expectations of a quick solution; the idea that one big change will solve all problems; a lack of connectedness between pedagogical theory and practice; and a failure to disseminate and implement practices that have had proven effectiveness. Perhaps the most popular big solution at this time is the belief that raising standards and including a battery of "high stakes" tests will improve student performance. But the shortcomings of testing are becoming evident—measurement does not improve performance unless accompanied by strenuous efforts to improve teaching and learning—and so American education seems to continue in an unending state of crisis.

Practices at CESAME have developed and expanded gradually, and they are still evolving. The Center does not claim to have a final answer or a grand plan that will solve the nation's educational problems. Those at CESAME do however see themselves as making an important contribution to the teaching and learning of science and mathematics—at all levels.

Stony Brook University: History and Setting Stony Brook University (SBU) in Stony Brook, Long Island was created in 1957 for the preparation of science and mathematics teachers. But the college's mission was almost immediately transformed, with a major emphasis on research and a charge from the New York State Board of Regents to become a university that would "stand with the finest in the country," in the sciences. Over the past 50 years SBU has indeed flourished as a center for learning and research, with departments in all areas of science, as well as schools of engineering, medicine, dentistry, pharmacy, and nursing. With these new priorities, the focus on teacher training was drastically reduced, and the school of education was closed.

Stony Brook did however continue to educate small numbers of future science and mathematics teachers. In 1999, the university established the Professional Education Program as the coordinating unit for education activities and initiatives. The science education program was moved to LIGASE (Long Island Group Advancing Science Education), directed by David Bynum, a professor of biochemistry; and LIGASE was the forerunner of CESAME. This center enhanced the science education program and strengthened it with clinically rich opportunities for teacher candidates. CESAME has not only restored a focus on science education, but has developed new strategies and models in teaching and learning science.

The university is located in Stony Brook, toward the eastern end of Long Island, a town typical of the area. It is an affluent, commuter region whose residents are business and professional people with high ambitions for their children. The local schools pay well, attracting quality teachers, and offering enrichment activities, advanced placement courses, and research for students. Brookhaven National Lab and Cold Spring Harbor Lab are not far, offering additional educational and research resources to the area's schools and colleges. From 2008 to 2012 an average of 20 percent of the semi-finalists for the high school Intel science competition came from Long Island's Nassau and Suffolk counties—indicating the very strong culture for high school student research. But within an hour from Stony Brook there are much poorer towns with many under-prepared students needing academic and social support.

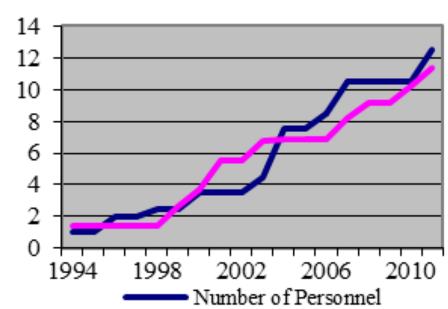
CESAME: Priorities and Activities CESAME's mission statement and discussions with the principal planners and administrators have identified the following as the Center's priorities:

1. Outreach to Schools and Districts: To provide educational and research experiences for students and teachers, particularly those from Long Island school districts, engaging and motivating them in science, while also teaching the skills and providing experiences required for state and national tests. These activities include teaching labs in the sciences that are visited almost every day during the school year, as well as summer programs at Stony Brook and at area schools.
2. Science and Mathematics Teaching, Leadership, and Professional Development: To build strong programs providing Ph.D. degrees in science education and masters degrees in the sciences and mathematics, educating science and mathematics teachers, specialists, and educators at all levels, with a commitment to active, exploratory learning for their students and ongoing professional development for themselves. Graduates of these programs are taking leadership positions in Long Island schools.
3. Funded Research Programs and Scholarships: To provide research opportunities, scholarships and fellowships during the summer and academic year, supporting and engaging students from high school to post-doctoral levels; funding doctoral and post-doctoral research and teaching fellowships.
4. New Courses and Curricula: To support faculty in the development of new curricula and courses that take students beyond the general course offerings to explore relevant topics, and to nurture developing interests. The Center has supported a major revision of the Introductory Biology program and eight newly established special-interest courses in biology.
5. Partnerships and Networking: To develop partnerships with departments and activities at SBU, as well as other universities and colleges, regional laboratories, and area businesses.
6. Research in Educational Practices: To engage in science education research. In recent years, the Center has hired new faculty members with strong backgrounds in educational research. They are conducting studies to determine the effectiveness and factors contributing to success in areas of introductory biology and physics, teacher assistant training, and other areas. This research is expected to be a central activity in CESAME's future.

The Origins and Growth of CESAME (Formerly LIGASE) The activities and organization that led to CESAME began in the early 1990's when David Bynum joined Stony Brook's Department of Biochemistry and Cell Biology. He obtained an NIH Bridges to the Baccalaureate grant to provide summer research for community college students, supporting their transition to four-year institutions. Through this and subsequent grants, Dr. Bynum created partnerships with Long Island community colleges and offered summer research opportunities to underrepresented minority students at these schools.

In 1994 Dr. Bynum received the first of four Howard Hughes Medical Initiative (HHMI) awards. The Center has grown through the years: obtaining laboratory space, faculty and staff lines, additional

Figure 1. University Support for Center for Science and Mathematics



university resources, and the support of Stony Brook University presidents. With additional grants, Dr. Bynum continued to grow the organization. He also hired an experienced university administrator with grant writing, finance, and leadership skills. Figure 1 shows the growth of personnel and space.

The goals of the first HHMI grant included: increasing the numbers of underrepresented students who choose careers in the biological sciences; transforming undergraduate biology education at Stony Brook into a more laboratory-based and research-oriented experience; supporting a newly designed course, Techniques in Molecular and Cellular Biology; providing summer and academic year research fellowships to undergraduates; and initiating summer research programs for students from high-needs high schools.

In 1995, Dr. Bynum took over responsibility for the Biotechnology Teaching Laboratory (BTL) that provides full-day biotechnology learning experiences at the university for middle and high school students. The teaching/learning modules are inquiry-based and focus on the New York State science standards. In recent years, teaching labs have also been introduced in chemistry, earth science, physics, and sustainable chemistry. Several thousand students visit the labs each year.

In 1996 Dr. Bynum worked with community college faculty and personnel from high-needs school districts to advance the teaching and learning of biotechnology in schools and community colleges. This activity resulted in an NSF Advanced Technological Education (ATE) grant to partner with the biology departments in the creation of biotechnology laboratories and curriculum, and to implement workshops for biology teachers. With a pipeline of underrepresented high school students, Dr. Bynum was awarded a National Institutes of Health (NIH) Minority Access to Research Careers (MARC) grant in 1997. The pre-award site visiting team met with about 30 minority students served by the ATE grant, which was an important factor in obtaining the grant. Over the years, more than 100 Stony Brook undergraduates have received MARC fellowships.

By the late 1990's, therefore, major funding had been obtained from HHMI, NIH, and NSF. 1998 saw the creation of the umbrella organization, Long Island Group Advancing Science Education (LIGASE), which was featured in an editorial in *Newsday,* Long Island's leading newspaper. Since receiving initial HHMI funding the number of undergraduates performing research at Stony Brook has increased by almost 50% and the number of underrepresented students majoring in the sciences has doubled. In 1997 Stony Brook was one of 10 universities in the nation selected by the National Science Foundation for a Recognition Award for the Integration of Research and Education (RAIRE).

With the 1998 HHMI award LIGASE continued its activity in revising the undergraduate biology curriculum, and the dean of the College of Arts and Sciences established a faculty line and committed $1.5 million to support the HHMI program and accompanying curriculum changes.

In implementing the 2002 HHMI award, Dr. Bynum extended activities beyond Long Island. LIGASE added courses, hired a faculty member, began awarding postdoctoral teaching fellowships, provided science lectures for the public, and developed additional opportunities for K-12 students and teachers. In 2003, Dr. Bynum received the Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring, given at the White House.

John Marburger, a presidential science advisor and former Stony Brook University president who supported the initial HHMI proposal, presented the award.

This NSF Presidential award included $10,000. Dr. Bynum in turn asked University administrators to match this amount and with the funds he created 14 fellowships, each with a full tuition waiver and a $5,000 stipend for pre-service teachers who would do their student teaching in high-needs school districts. These fellowships led to an NSF Robert Noyce grant awarded in 2005, providing scholarships for prospective teachers in high-needs school districts.

Institutionalization While LIGASE grew as an educational center, offering professional development to teachers, and exploratory learning to students, Stony Brook was expanding its Professional Education Program (PEP). This program provided teacher preparation and certification in secondary school teaching in the humanities, social studies, languages and the biological and physical sciences. The program used a model that housed content courses within the appropriate departments, while the pedagogy courses were located where the best resources could be found to provide the appropriate conceptual background, skills, and clinical experiences. For the biological and physical sciences this location was LIGASE.

In 2001 LIGASE took responsibility for the pedagogical and clinical preparation of future teachers in biology, chemistry, physics, and Earth science. At about the same time, it became clear that the course load and teacher preparation for undergraduates in the sciences would be quite heavy, and so a five-year program leading to the BS and MAT degrees was introduced in 2004. With this innovation, enrollments in the undergraduate science education programs decreased, while the graduate MAT programs grew.

In 2007, the Provost added the mathematics pedagogical components to LIGASE. The university also transformed LIGASE into the Center for Science and Mathematics Education (CESAME) with Dr. Bynum as its founding director. In his message to the University community concerning the establishment of CESAME, Provost McGrath noted:

> LIGASE directs programs ranging from elementary school to in-service and pre-service teacher education, to the post-doctoral and faculty levels. LIGASE has received over $12.7 million in external grant support and is nationally recognized for outstanding programs at all levels. Many of these grants cut across department lines and LIGASE has written successful grants with faculty from Engineering, Physics and Math. There is strong curricular demand for integration of these subjects, at both the K-12 and university levels, and many potential future funding sources support this integration. I believe Stony Brook University is especially well suited to participate in, and lead, the development of the next generation of teachers and teaching strategies in science and mathematics. It is time to create the Center for Science and Mathematics Education where the intent is to expand to all science and mathematics successful practices that have been developed in LIGASE.

In 2007 Dr. Bynum hired Keith Sheppard, a science educator from Teachers College, Columbia University to direct CESAME's science teacher education programs and to create a doctoral program in science education. Dr. Bynum also began to work with Dr. Sheppard on a succession strategy to prepare him to direct all of CESAME's activities. Dr. Sheppard received a fast-track tenured appointment in 2008 as associate professor in the department of Biochemistry and Cell Biology. In his first five years at Stony Brook Dr. Sheppard had 10 publications, 19 presentations at national conferences, and became the principal investigator on two grants with support exceeding $1 million.

In place of a school or department of education, Stony Brook uses a distributed model for its teacher education programs. Within this model, CESAME—working closely with the various science departments—serves as the focus and home for the science education programs (Biology, Chemistry, Earth Science, Physics, and Mathematics).

In 2009 NCATE's (National Council for the Accreditation of Teachers) Board of Examiners reviewed Stony Brook's programs in initial and advanced teacher preparation. The report from the visit stated that the program met all six of the initial and advanced standards; and for the initial teacher education programs all standards were met with no areas identified for improvement. The report cited two particular strengths: (1) the distributed model in which, "faculty are masters of both content and pedagogy." The report found the model well suited to a research university (p. 35). (2) CESAME is commended for providing, "considerable community outreach services to K-12 students and their teachers." In this effort, the report mentioned the teaching labs and the summer programs.

This university's designation and recognition of CESAME was important, locating the Center within the university structure, providing sustainability, so that continuity was no longer entirely dependent on grants. CESAME thus began a more formal integration of activities with the mission of the university and the Center developed a five-year strategic plan to work toward the following goals:

- Provide leadership in science and mathematics education;
- Become a nationally and internationally recognized center of excellence;
- Increase the quality, quantity and diversity of the nation's science and mathematics talent pool;
- Enhance and support increased K-12, business and university partnerships;
- Expand external support opportunities for the university.

Throughout this report we will discuss the implementation, outcomes, and impact of the different programs sponsored by CESAME. Before that, however, we want to situate the program in the context of education generally, and particularly in the United States.

2. Science and Education in Today's World

CESAME is engaged in education at all levels and in a variety of circumstances. To understand the environment and the challenges facing the Center we should step back from the day-to-day activities and consider some of the significant issues in science education.

Science and technology have always been important in understanding and interacting with the world. But in recent years the impact of science has expanded into every area of life—bringing both benefits and challenges. It is therefore most important not only that schools prepare the next generation of scientists, but also that science be taught effectively so that the principles and practices that grow out of science and technology are understood by the broad population of children, young adults, and in fact people of all ages. By way of example, we suggest a few important issues in the areas of health, the environment, and the digital revolution.

The vast arenas of health, nutrition, and exercise affect each of us every day. Biology that used to focus on classifications and chemistry that focused on the periodic table are no longer adequate to prepare students for a complex society. People want to understand how their bodies work, and how to maintain health. Those planning for a future in any of the health-related careers—including medicine, nursing, and allied health—must not only learn the basics of the disciplines but, at an early age, should become engaged so that they not only learn but also do science.

With regard to the environment, all of science and science learning will be useless if we humans destroy our habitat. Science is telling us that time is short. And yet to take the necessary corrective action will require that the best minds find the appropriate technologies and that governments, corporations, and individuals work together, exploring remedies and alternatives. Effecting change will also demand a well-informed public and electorate.

The digital revolution has provided us with access to vast stores of information, available almost instantly. But knowledge is not wisdom and facts without analysis do not solve problems. Similarly, the fact that we can communicate quickly does not mean that we have something useful to say. And so science must be interpreted in light of its uses, and complemented by ongoing review and analysis, to determine whether outcomes are achieving desired goals and whether these goals are consistent with a harmonious society.

Recognizing these and other trends, CESAME's plans and activities are based on a comprehensive view of science, mathematics, education, and society. The Center is always looking at promising new activities, and new populations to serve. The Center began with a focus on biology, but over the years has expanded so that its courses, programs, and staff now cover all major areas of science and mathematics. CESAME has evolved, adding faculty, space, and a continually expanding view of science education.

The Goals of Education American education has its roots in an agrarian society and in the industrial revolution. When 90 percent of the population lived on farms and children began working at an early age, long vacations from school were needed. They were generally in the spring and fall and not in mid-summer as is often assumed, but they established a pattern of lengthy interruptions in schooling. The industrial revolution of the eighteenth century found efficiencies in the uniform methods of mass production. Both the efficient methods of production and the fact that graduates would likely remain in one career for their working lives led to an educational system that, at the elementary and secondary levels, employed practices requiring rote learning and the rigid application of rules, as opposed to learning that stresses creativity and problem solving. In addition, the student learners were generally treated as passive vessels to be filled with knowledge. We should not assume however that all past practices were harmful. Young people in school often developed productive work habits, memories that served them well, and a fund of basic knowledge. But with changing times, changes in schooling were needed.

There have of course been numerous calls for reform and for a shift in priorities, with countless starts and stops, and detours along the way. Teachers often joke about the fact that educational ideas and practices come and go, and then return again. In many ways they are right. Nearly 100 years ago John Dewey (1915) described plans and practices for how education, play, work, community, and democracy should be integrated. "Education," he wrote, "is not a preparation for life. It is life." It is noteworthy that many of his ideas and recommendations are returning.

Fifty years ago Harold Gardner (1961) wrote about the tensions and ambiguities inherent in a system that strives to educate while guided by the twin priorities of equality and excellence. The nation is still struggling to meet the demands of this project. Also, about fifty years ago there was a national call to improve science education, in the face of challenges from the Russian space program.

Some of issues in education can be addressed by distinguishing among different goals. Discussions could be simplified if people agreed on which goal they were considering. The following four general goal areas can at least provide a framework in which to discuss, plan, and assess progress.

- *Maintaining the Tradition.* In the process of education, each generation shares and hands on its culture, skills, values, wisdom, and much more, to the next generation. Advocates and practitioners of the classical education believed that the study of ancient languages, mathematics, rhetoric, and certain other prescribed areas trained the mind and put one in contact with the great ideas that form the foundation of our culture. While these goals and practices have shifted, we still have the responsibility to pass along who we are and how we have gotten to this point. Science, history, literature, and art are all works in progress.
- *Individual Growth and Development.* Education assists individuals find and cultivate their potential so that each can gain the satisfaction that comes with growth and achievement, directed toward individual and social ends. The rise of modern science and the focus on individual freedom made this goal more prominent. Teachers while engaging students in the great ideas and practices of the past and present, should always be alert to students' individual talents and interests. These bring learning to life and often give the learner a sense of direction.
- *Career Preparation* Students must be prepared to enter the workforce in a changing world. Effective career preparation should be integral to education, and become clearer as the student moves through the process of schooling. It is now understood that those entering the workforce need both general analytical and problem solving skills along with an array of technical, communications, quantitative, and literacy skills.

- *Participating in Society* Education should provide students with an understanding and appreciation of community and government at all levels. A nation is in danger if citizens take for granted what earlier generations have won at great price. Education must therefore equip the individual to participate in social and political processes and organizations.

Each of the goal areas requires the development of plans to accommodate all students, bringing them to basic levels of literacy, numeracy, and cultural awareness so that they can then find and develop their inner talents, be well prepared for careers, and be able to play constructive roles in our democracy. Science and science education are also embedded in each area.

The twentieth century witnessed a shift in educational priorities at all levels. The traditional goals and methods of science and mathematics came under attack. "Training the mind," and "improving memory," were valued less while exploration, problem solving, and practical usefulness were valued more. In any case, we believe that identifying the four broad areas of educational goals can clarify discussions about what we are trying to accomplish in schools and colleges.

We can consider the four goals as related to biology. There are both broad theoretical areas and many minute facts to be learned. The big ideas such as evolution and the many details must be taken together to form a foundation; and this aspect brings students into contact with the tradition. Individual students will then find that they are more attracted to one area than another: the workings of molecules or proteins, the remarkable evolution of species, and so on. Individual engagement offers motivation, focus, and intrinsic rewards. If one selects biology as a component of a life's work, there are many areas in which, with appropriate training, employment may be found. Finally, the many areas of biology are of great importance in public life—in medicine, environment, climate, and much more.

Issues in American Education Keith Sheppard (2006) of Stony Brook University points to a cyclic process in American education: declare a crisis/commission a study/issue a report/make a call to action/make little substantive change/declare a crisis… The crises have been real; the studies generally accurate; the reports drafted with useful recommendations. But the actions taken have generally been insufficient to effect real change. And so there has been a recurring reversion to the status quo.

Several studies elaborate on this thesis. Wilson & Davis (1994) contrast the methods of the educational profession with those employed by other areas such as farming, the airline industry, and medicine. These other professions follow a path of continuous improvement driven by established procedures and the contributions of both practitioners and specialists. For example, after experiencing a crop failure, farmers consult with one another, visit their extension offices, and try different nutrients, until they discover what is happening and, if possible, solve the problem. Surgeons in different parts of the world use similar methods and exchange information about improvements; in addition, these professions generally understand incremental change. A discovery or improved practice in Geneva, for example, is soon studied and adopted or adapted in Chicago. Finally, if something of value such as a motor with proven success breaks down, it is studied and fixed or improved, not rejected as radically flawed. The authors find that these approaches are not generally practiced in American education.

Following up on this thinking, Stiegler and Hiebert (1999) studied the different approaches to teaching and professional development for educators that are used in the United States and in Japan and Germany. They suggest that teaching is more a culture than a profession. As a culture, teaching and learning in school contain an array of assumptions and practices that are absorbed over a period of years, and are rarely questioned. As a result, researchers report that teachers say that they value certain studies and reports and that they are following recommendations, when in fact they have not made significant changes. In Japan, by contrast, teachers spend a great many hours discussing the details of an individual lesson, examining student responses, and making improvements. As a result, they can point to 50 years of improvements. The authors suggest, based on history, that American educators prefer failure to incremental improvement. We will suggest several other issues in American education and then discuss activities of CESAME and how they address these issues.

Inequality and Diversity. The word "equality" has many meanings when applied to education. Supreme Court decisions handed down in 1896 and 1899 held that "separate but equal" could legitimately be applied to public education, meaning that segregation was legal. In 1954 the Court overturned these decisions, finding that in the case of segregation, "separate" was, in practice, inherently unequal. We live in a country still plagued by racism. Poverty, inadequate resources, a lack of public concern and other factors have conspired to hinder the progress of African American, Hispanic, and poor students.

The National Science Foundation and others have documented the fact that African American, Hispanic, and Native American students are underrepresented in the STEM (Science, Technology, Engineering, and Mathematics) disciplines—with regard to numbers of students in the majors, degrees earned, and entrance into graduate school. The discrepancies become greater, moving up the academic ladder.

There is general agreement in the academic community and beyond that efforts should be made to remedy the situation. Several reasons can be given for making this effort (Miller, 1995). First, the productivity of the entire nation depends on the achievements of everyone. Second, civil rights benefits that have been gained will be furthered only if minority students gain the educational background required for their next steps. Finally, the maintenance of a just society requires that minority students achieve at a rate comparable to the population at large.

"Diversity" is a term frequently used in today's educational world; it suggests a positive perspective on the issues of inequality. Creating a more diverse corps of teachers at all levels and encouraging the inclusion of more under-represented minority students in the sciences will benefit not only the students themselves but also future students and the educational institutions as well.

This report's discussion in Chapter One described some of CESAME's efforts to work with minority-serving school districts, to provide research and bridging programs for minority college students.

Research in Science Education Research in education often starts with questions about student learning. Teachers use a variety of methods to determine whether their students are learning and performing in ways consistent with program objectives. And so educational research looks for evidence that particular teaching and learning methods, activities, materials, and the like are effective.

Educational assessment varies based on the discipline, goals and other factors. A teacher or researcher uses different criteria and methods to assess a student's outcomes in art, mathematics, biology, and writing. Similarly, educational research borrows its methods from other disciplines—psychology, sociology, and clinical medicine, to name a few. But educational research has developed a body of literature and a set of methodologies such that practitioners look to them for guidance in studying the practices in teaching and learning.

Perhaps the closest analogy to educational research is medical research. Both consider: theory and practice; success described in terms of health or learning, as well overcoming disease or remediation regarding learning difficulties; and both consider issues in translating successes with individuals or small groups in controlled settings to large populations. Researchers in both areas need to proceed modestly, recognizing that there is still much to be explored. Further on in this report we will discuss educational research in greater detail.

Disconnect Between Primary/Secondary and Post-Secondary Education Venezia et al. (2013), in a thorough and carefully documented study, described the many ways in which weak connections between the K-12 educational system and college education in the United States "betray the college dream." They pointed to a significant lack of agreement between high schools and colleges in approaches to teaching/learning and assessment. The statistics alone are challenging:

- The graduation rate from high school is 69% overall; 54% for Latinos; 56% for African Americans
- More than 60% of students in community college must take remedial classes.
- In New York State only 61% of high school graduates and 40% of African American graduates receive the State Regents certificate. The Regents curricula, upon which the exams are based, provide minimal preparation for college.

Beyond these statistics, the study points to a variety of ways in which there is a mismatch between high schools and colleges. But the authors also point to avenues for solutions that include:

- Exposing high school students to college experiences;
- Incorporating technology into the learning process;
- Prioritizing teacher training;
- Redesigning the high school experience;
- Initiating targeted interventions;
- Adopting national standards;

These issues provide a useful framework and set of reference points as we discuss the activities and progress of CESAME. We now mention several other relevant issues. These issues are more practical and immediate than those discussed above.

Scores and rankings of the American students compared with those from other countries, vary according to the year, test, and subject area. The most recent results from PISA (Program of International Student Assessment) are about the same as the other tests of recent years, showing American 15-year-olds "around the average" in reading, math, and science compared with the rest of the world, and lagging considerably behind the leaders.

There seems to be a belief among educational administrators and policy makers in the United States that more testing, with improved standards will improve student performance.

This belief may be due in part to the results of international testing. But it may also seem easier to focus on clear learning outcomes than on the complexities of teaching and learning, and long-term approaches to teacher training. Although most will admit that measuring alone cannot improve growth in any area, there is nevertheless a conviction that clear learning targets, with teachers and students being held accountable, will lead to improvements.

Based on real results and available evidence, it seems we should pay more attention to teacher training and professional development. In 2009, Finland surprised the world and itself by scoring highest in one of the better-developed international tests (Ripley, 2013). The results should not have been a surprise. During the 1970s and 80s Finland closed its teacher preparation colleges and opened new ones on the campuses of ita leading universities. Standards for entry into these teacher preparation colleges were raised so that admission is now as academically demanding as is admission to medical school. This is educational reform that goes to the heart of what is needed to effect change. Success in international tests surprised Finland's educators because they had not focused on testing: they focused their efforts on improved teaching and learning.

Stigler & Hiebert (1999) described in detail the teaching that has taken place in middle school mathematics classes in the United Sates, Germany, and Japan. There were significant differences. In essence, the greatest difference was that German and Japanese teachers guided students patiently through complex thinking to solve difficult problems. The students were engaged, wanting to achieve success. In the United States, teachers generally worked quickly, looking for short answers, while requiring only superficial attention from teachers. In addition, it is not a coincidence that the nations scoring higher than the United States on international tests all had significantly longer school days and school years. This added time allowed for more learning, at a more reasonable pace, and less learning loss—particularly over the summer.

Entrepreneurship and Education Of the 85 institutions in existence since 1522, 71 are universities. (Thorp & Goldstein, 2010, p 5) Is this durability due to their allegiance to core principles or is it because they adapt to changing times? Perhaps as in the case for the longevity of a species, it is both. Long-lasting organisms have a core structure that withstands the assaults of the elements and enemies, but they also adapt to changing environments.

American universities are heirs to a great tradition of scholarship, research, and teaching/learning. They attract faculty, researchers and students from all over the world—at least in part because of the spirit of innovation and the productive teamwork used to solve problems. Thorp and Goldstein comment that in our universities there are scientists who are discovering what is, and engineers who are creating what never was. The "engineers" can be compared to translational researchers in medicine, mathematics, biology, and other areas of science. This translation is not simply the application of a principal, for example of physics or nutrition, to a practical situation as in the building of a motor, or the preparation of a better diet. Rather the practical application is itself an important area of research. This can be seen in the development of robots or in clinical trials in medicine. In each case, there are great numbers of problems, strategies, trial and error tests, and other issues to be addressed. The researcher does not know from where a solution might come, and so the innovative spirit is essential.

Education is very much in need of translational research. Recent years have seen advances in cognition, in studies of the brain, in social learning, in the development exploratory activities. But we are still struggling to determine how to use all of these findings to build better approaches to teaching and learning. Entrepreneurs are also needed.

Universities and other educational organizations function within both structures and cultures. Structures include the departmental arrangements, with established procedures for promotion and recognition. While departments can differ widely, the overall silo structure tends to militate against entrepreneurship in teaching and learning. The spirit of entrepreneurship is more readily found in research.

The culture of an institution consists of an array of unwritten procedures, relationships, communications networks, and reward systems. A leader can create a culture of entrepreneurship by focusing on the organization's mission and effective problem solving, rather than on rank, tenure, and procedures. As in the private sector, funding can be a key ingredient. A successful entrepreneurial start-up is identified by its profits and growth. An educational start-up needs funding and often the size, continuation, and growth in funding contribute to success. "Making connections, encouraging conversations, and collaborating are essential elements of entrepreneurship. … Interdisciplinarity is the wave of the future" (Thorp & Goldstein, 2010, p 68, 70).

Kao (2007) made a several important points about entrepreneurship and leadership in education that are particularly relevant to Bynum's work and CESAME's success.

- "A broad mission is empowering, providing creative people throughout the institution the encouragement and space they need to innovate" (p. 86). This is a key strategy. Those teaching in CESAME's programs know that they have the freedom to innovate within the broad mission of creating "exciting science."
- "It (entrepreneurship) is the blending of the intuitive and practical, the optimistic and the pragmatic." Again, Dr. Bynum uses very similar words when describing what he is trying to do. He "knows" that certain kinds of outreach summer programs, competitions, and the Biology Teaching Lab are good for students and teachers. He intuits the benefits. But the structures must be thoroughly practical if the benefits are to be realized.
- "The job of the innovative leader is to create a culture, not tinker with rules," (p. 86). CESAME does not have restrictive rules. There are expectations and faculty must fit into the university's procedures. But rules do not stand in the way of creative plans and activities.

This sketch of educational entrepreneurship is relevant to CESAME in several ways. Under Bynum's leadership, the organization has incorporated a number of the ingredients associated with entrepreneurship, including:

- A focus on the mission, exploratory, research-based science teaching and learning at all levels;
- Acquiring teachers and mentors who energetically engage themselves in the Center's mission;
- Successfully increased funding and other resources, through grants, fees, university participation, and private donors;

- Looking for new challenges that will expand the Center in directions consistent with its mission, history, and resources.
- Developing a network, within and beyond the university, of like-minded people dedicated to improved teaching and learning.

3. Research Programs for Students

As discussed above, CESAME's first activities (as LIGASE and before) consisted in reaching out to area schools and students. The programs made college level laboratories, equipment, and faculty members available to community college, high school, and middle school students. Chapter One offered an overview of the activities; in this chapter we provide greater detail about the dynamics and benefits of certain student research activities. The following programs share certain common features. But each has its own distinguishing characteristics. The common theme is that students are offered the opportunity to do real research. They experience the excitement and the frustrations that accompany attempts to plan and carry out something new, even in a small way. The differences among the programs are related to: the timing—summer or academic year; students—Stony Brook or other; the level of students—high school, community college, college; and the intensity of the research—a day, summer, or longer.

Bio-Prep Summer Program for Community College Students The NIH-sponsored Bridge to the Baccalaureate (BioPrep) program for community college students was Bynum's first grant at Stony Brook and has been sponsored by CESAME for more than 25 years. During that time the substance and foundation of the program have remained, emphasizing laboratory skills and mentored research, while the strategies and methods have been reviewed and improved over the years. The program's first two weeks are devoted to the development and practice of lab skills and the final four weeks involve group projects. The following review of the program is based on evaluation studies, which involved discussions with the program faculty and group interviews with the students.

With several iterations of the program, faculty introduced possible research project topics earlier—at the pre-program meetings in the spring. Some students identified areas of interest and were thus able to begin readings and the program could acquire materials as needed. In one case, a group of students continued a project that had been started two years earlier and then carried it on during the academic year under Dr. Moloney's direction. Overall, the staff generally found the students to be highly motivated and energized by the research experiences.

Students reported learning about the program from several sources: professors, program literature that was distributed at their community colleges, posters and online messages. In most years, they came from three community colleges that have had an ongoing relationships with the program—Suffolk, Nassau, and Queensborough. In the group discussions the students were enthusiastic about the summer experiences. In recent years a sister program has been implemented. It attracts students from community colleges all over New York State. The following consolidates material from several evaluations.

<u>Research Skills</u> The program faculty and students reported that the lab skills—pipetting techniques, DNA extraction, and other methods—were new to most of the participants. The staff members were somewhat surprised but reported that the students learned the skills quickly and were able to use them effectively. Students commented,

- *We used them every day in the research projects.*
- *It's a matter of learning both theory and practice.*
- *Using them is better than just learning something and checking it off.*

- *We learned a lot of skills and became pretty good at them.*
- *Most likely the things we have learned will come up in courses and will be useful in further research; they are basic skills that you should have as a researcher.*
- *Even if you don't use it, the skills gave us an understanding of the ideas.*
- *We also learned how to budget time.*

Research Projects The earlier selection of topics provided some students and groups with additional time to learn related information, read articles, order materials, connect the skills to the projects, and in general consider what they hoped to accomplish. Students were articulate as they described strategies, conditions, frustrations, and adjustments they made. They commented:

- *We had ideas and we brought them to our instructors and they helped us clarify and refine them.*
- *Our group succeeded more than we expected and more than Dan expected.*
- *We worked on longevity; we started with something very general; we got some results, but not all that we had planned.*
- *We made some of our own materials.*
- *Our project was on cloning genes associated with autism; we tried to see if there was any change in the protein.*

When asked about the qualities required in a researcher, students listed patience, determination, persistence, curiosity, and hard work. They gave examples of how these were needed in their own projects.

- *We tried, repeating the process for two weeks, and just got results yesterday.*
- *You have to really want the answer, and not for someone else.*
- *We were successful but we were not able to do all we had hoped for.*
- *You need patience because you have to do things over and over; trial and error; 9 out of 10 experiments will probably fail.*

When asked about the background needed for research, and how this was provided so that they were not functioning simply as technicians, the students said that their mentors would take the time to explain what was needed, and would provide references so that they could look things up. They reported that discussions would start on something in their projects and then continue on to other related areas.

I had read about a lot of these things, like extraction, but didn't know what they meant. Now I am very comfortable with them.

The program is successful in combining research and mentoring. Students are immersed in a topics of their choosing, acquiring the practical skills and theoretical underpinnings as needed. The process is very different from typical classroom learning.

She gave us a whole bunch of articles and from those we learned how to frame an experiment.

In discussing the benefits of research, the students commented that there is still a great deal to learn and they mentioned the practical applications that some of their lab supervisors are exploring, in cancer and in the way certain proteins interact.

Describing the work of their research teams and of the scientific community in general, students pointed to a number of ways in which teamwork is effective.

- *One person cannot do everything related to a large project.*
- *People have different skills and interests and so it is good to divide the work according to their strengths.*
- *It is very helpful to review results at the end of the day, checking each other's understanding, and explaining the material to one another.*

With some prompting, the students were also able to expand on ideas of teamwork and enunciate the broad outlines and benefits gained from participation in the scientific community.

Presentations: Experiences and Skills Most of the students commented on how little previous experience they had had in making oral presentations in their college classes. Some said they were apprehensive about the four required presentations for the summer program. But all said they benefited from the experiences, gaining skills and understanding in the process. It is surprising that such an important life skill is ignored in large parts of the undergraduate curriculum.

The students commented on the experience gained preparing PowerPoint and poster presentations. They described not only acquiring skills but also gaining new insights into the material and making connections as they presented their ideas and projects.

- *It's good that we had a presentation almost every week; you are forced to learn what you are doing; you don't want to go up there and be clueless.*
- *We learned a lot of skills, now I want to take a class in speaking.*
- *We were told to prepare a PowerPoint over the weekend. I hadn't done one before; so I learned a lot.*
- *There are a lot of posters around and online; and they gave us examples of abstracts.*
- *I'm a little worried about my communications skills, Nicole (another student) helped me a lot with pronunciation.*

One student described the difficulty in presenting data that was ambiguous. The faculty mentor who worked with them explained how to deal with the issue.

It was really hard because some of the data didn't look good and we weren't sure it would help. Kristin showed us how to make it fit and taught us some of the techniques that made it look awesome.

Future Education and Careers Most of the participants were new to research and were very much engaged by the experience. Several said that they definitely wanted research to be part of their continuing undergraduate studies. Some expressed a serious interest in careers devoted to or including research. Some thought it was a most important experience even though their primary career interests were in other areas.

- *This is the first research I have done; I want to go to medical school; my instructor told me to get some background; I never heard of an MD/PhD. I would like to work with doctors without boarders.*
- *I'm definitely going to do research. This really opens up your mind and lets you know there are so many possibilities; that you can do research while you are going to school.*
- *It opened up a lot of possibilities for me; I still want to become a nurse, but if I want to change I can see other possibilities.*

- *The experience has reinforced what I thought I wanted to do: I want to go into medical research.*

Speakers The program included weekly guest speakers. The students responded positively, finding that the speakers brought a wealth of useful information and experience.

- A speaker from the admissions office explained the transition from community college to four-year institution, including the application and acceptance process. The speaker also described the different opportunities at Stony Brook. She said she would be available for individual consultation. Several students took advantage of this, meeting with her and through these meetings at least one student went on to meet a department head and discuss opportunities. Several students in this cohort were accepted at Stony Brook.
- The director of undergraduate biology described the curriculum, the sequence of courses, research opportunities, and many other details of the Stony Brook program. The students found this presentation to be most helpful, giving them a practical sense of what the next stage in their education might be like.
- Several speakers talked about their research, giving the students a deeper sense of applied science and how laboratory procedures need to be reworked, for example, as potential cancer therapies.

Summary This summer internship program appears to be extremely well organized not only in the arrangement of experiments but also in presenting scientific research at the right level for the participating students, so that they are challenged but not overwhelmed. The following were the benefits most frequently noted by the participants:

- They worked very hard, harder than they ever had before, but did not find this hard work to be unpleasant or burdensome. This is an excellent lesson for college students to learn: work is work but it can be satisfying.
- They gained extraordinary insights into the breadth and depth of scientific research and the applications of research.
- They experienced a surge of confidence as students and young researchers.
- They learned that teamwork can be productive, enhancing the progress of scientific research.
- They found new possibilities, regarding future education and career options.

Biology Teaching Lab In 1995, Bynum included the Biology Teaching Lab (BTL), in the first HHMI grant. Since that time, more than 55,000 K-12 students have visited the university to take part in the BTL. With the participating school districts paying an average of $22 per student, per visit, the activity has generated about $1 million in revenue. The Center's leadership is proud of the fee-for-service model and the self-supporting nature of the activity. The school districts are pleased to send their AP and New York State Regents biology students to the labs because the activity offers important experiences that the schools cannot provide.

Joan Kiely, long-time director of the BTL program, explained that they have five lesson modules, each one running from 4.5 to 5 hours. They also provide some forensics labs for second-time visits or classes not directed toward the SAT or Regents exams.

The experimental work is in the area of molecular biology and includes topics such as manipulating DNA with gel electrophoresis. She explained that, "we have the procedures written as clearly as we can so they can work independently without being walked through." And she explained, "We leave openings whether they want to do A, B, or C. So they make some decisions; and whatever they do, they will have some measure of success."

But she explained that in conducting the labs they also wanted to reinforce the school programs and consequently they are in touch with teachers about what would be helpful or what might be missing from the laboratory programs at the schools. "So we talk to teachers before they come, asking about ideas they would like reinforced, and things like that. And then we ask about the class; how independent the kids are and whether they can work in groups."

Teachers cited a variety of goals for visiting the BTL They reported that these goals are achieved with each visit. The goals included:

- To expand students' horizons;
- To provide experiences in an advanced lab with facilities otherwise not available to them;
- To do the required labs for both courses (AP Biology and Regents), particularly, bacterial transformation and DNA restriction.
- To let seniors gain some experience of college life.
- To have students do the forensics work, DNA techniques, and understand evidence, "things you can't do at school."
- To let students hear those at the university talk about things that are discussed in school science classes. "Then they realize how widespread and important biotechnology is."

Teachers reported that students generally responded enthusiastically to the BTL experiences. Although some said that the day could be a little long for some students, others said they were surprised at how involved the students remained all day. Teachers also commented that students go back and tell others at the schools about how good the program is.

With regard to recommendations, the teachers said that the CESAME staff is continually improving the program and is open to suggestions. One teacher suggested occasional school visits and talks by the BTL staff. All expressed the hope that the program will continue indefinitely into the future.

In a careful study of the impact of the BTL, Kiely and Kelly (2014) reviewed some of the deficiencies of pre-college science education in the Unites States, mentioned above. They also cited other studies that have examined the benefits to school teachers collaborating with university scientists. They commented that middle and high school students have been at a juncture when they might begin to see themselves as future scientists, given the right kind of experimental experiences. The authors came to the following conclusions based on the data from surveys of students and interviews and focus groups with pre-service and classroom teachers.

> Data have indicated that this program significantly increased students' confidence, science knowledge, and interest in science. Teachers reported strong correlation between the BTL curricula and school-based course material and were highly satisfied with the program. Pre-service teachers refined their skills in pedagogical content knowledge in biotechnology, classroom/laboratory management, ability to assess prior knowledge, and time management.

In-service teachers who accompanied their students deepened their content knowledge by observing scientists engaging in cutting-edge research techniques. Both teachers and students gained an appreciation for critical questions in current biotechnology research, improving their scientific literacy and understanding of recent advances in the field.

Minority Access to Research Careers (MARC) In 1997 Bynum was awarded a MARC grant that offered stipends to undergraduates engaging in research with scientists at the university. These awards are intended primarily for under-represented minority students with the expectation that they will acquire the skills and motivation to propel them to graduate school. Students in the program are expected to maintain a 3.0 GPA and spend at least 15 hours a week in research, generally in a lab. The following is taken largely from the 2012 evaluation report on the MARC program. The findings are typical of evaluation of the MARC program at Stony Brook for other years.

The re-funded MARC program has completed three years at Stony Brook. In April 2012, interviews were conducted with all the MARC students and with Dr. Maloney, the program director. In May, the MARC fellows completed an online survey reviewing the benefits of the program as well as their experiences and reflections. The interviews and a visit to the undergraduate research celebration focused on how research had affected the fellows, the resulting benefits to their college learning, and the impact that the program might have on their futures.

<u>Benefits of Participation in MARC and Research</u> When asked about the benefits of participating in the MARC program and their research experiences, students identified a number of important program features.

- Half of those interviewed said that without the funding they would have had to work as much as 30 hours a week, earning money for tuition and expenses. The program, they said, was a double benefit—providing needed financial assistance and offering an opportunity to gain research experience. One student said, "Last year I was in a lab but could not give it the time needed because I was also working."
- Several MARC fellows talked about learning how to manage both course work and their lab responsibilities. In the past, this issue was sometimes seen as a problem. This year it was mentioned in a more positive way—as something that students felt needed to be learned and incorporated into their lives. Students also reported that the experience also showed students what graduate school might be like.

  I feel like for me, I wanted to do research, but I never had a sense of what it was like to be in a lab, and to manage schoolwork and research. But being around graduate students gives you a sense of what it will be like.

- As in the past, the students said that the experience gave them a more realistic understanding of what it means to do science, rather than simply learn science.

  Before we started I didn't know what research was; the experience changed my view of science and I will carry that knowledge with me. What you read in textbooks and in class is one thing; in lab you do it more in depth.

The survey provided statistical summaries of MARC students' experiences. Results of the survey items shown below were highly positive, with most of the means greater than 4.5 on a 1

– 5 scale. The MARC fellows reported: an expanded interest in research; a deep appreciation of their mentors; that research is more demanding than they had thought; and that they plan to attend graduate school and work toward doctoral degrees. Participants did not agree in large numbers that the program had raised their grades. This has been seen in past surveys. Although students say they find benefits to their courses from research, the connection is not necessarily evident in grades. The following table summarized the survey results.

For items 1-13, select the response that best describes your MARC experiences. The rating scale was: Agree Strongly, 5; Agree, 4; Neutral, 3; Disagree, 2; Disagree Strongly, 1. The only item for which some students selected Disagree or Disagree Strongly was #7, 'The program has taught me that I am not cut out for research.' For ease of reading, the Disagree and Disagree Strongly columns are not shown.

Table 1. Experiences in the MARC Program (N = 8)

Answer Options (N = 8)	Agree strongly	Agree	Neutral	Rating Average
1. The program is expanding my interest in research.	7	1	0	4.88
2. In the program I have learned a great deal about research.	5	3	0	4.63
3. The program has made a difference in my career interests.	3	4	1	4.25
4. My mentors are important to my success in the program.	7	1	0	4.88
5. Research is more exciting than I had thought.	4	4	0	4.50
6. The financial aid is very important to me.	8	0	0	5.00
7. The program has taught me I am not cut out for research.	1	1	1	2.50
8. I have found that there is a lot of teamwork in research.	4	4	0	4.50
9. Participating in the program has raised my grades.	0	3	5	3.38
10. Research is more time consuming than I had thought.	1	7	0	4.13
11. I will include research in my career goals.	7	1	0	4.88
12. I have made significant progress with research skills.	6	2	0	4.75
13. I plan to attend graduate school and earn a Ph.D. degree.	7	1	0	4.88

<u>The Value of Research</u> The MARC fellows were asked, in discussion, to reflect on the value of research. The question led to an interesting discussion. Some took the question to be asking what practical applications might exist for their research.

A student working on fuel cells said, "I think my research is important because there has been a lot of development in technology. Many devices need an energy source. We need alternative sources."

A student working in a cancer research lab said, "I work in a chemistry lab. I am working to synthesize a drug used in colon cancer. I'm going to test it on cancer stem cells."

With continued discussion some students talked more generally about the value of research in the expansion of knowledge. Others looked more globally at the value of research, as a quest for knowledge.

- *Research adds to our knowledge; you never know what will be a practical use for research findings.*

- *Research helps you understand how things work. And if we understand how they work, we can know better how to fix them if things go wrong.*

Experiences and Opportunities A subsequent set of survey items asked students to rate the level at which the program provided certain experiences and opportunities. The “low level” and “not at all” columns received no entries and are not shown.

Table 2. Features of the MARC Program (N = 8)

Rate the level at which you feel the MARC program provided the following.	To a very high level (5)	To a high level (4)	To a moderate level (3)	Rating Average
14. Opportunities to talk with faculty mentors	2	6	0	4.25
15. Developing skills and concepts needed for research.	4	3	1	4.38
16. Meeting people with similar interests	6	2	0	4.75
17. Experience in thinking about research issues	5	3	0	4.63
18. Preparing results for publication and/or presentation	5	2	1	4.50
19. Clarifying career goals	5	2	1	4.50
20. Reviewing relevant literature.	6	1	1	4.63
21. Designing research projects.	4	2	2	4.25
22. Collecting research data.	6	1	1	4.63
23. Analyzing research data.	5	2	1	4.50

Presenting The MARC fellows noted a variety of benefits from their experiences presenting in oral, written, and poster formats. These benefits included:

- Learning to present to different audiences, to interact with people of different backgrounds and interests, and to answer questions. Comments referred in part to the annual URECA celebrations as Stony Brook, at which hundreds of students present the results of their research. Undergraduate researchers do not always gain the perspective and breadth that come with presenting to non-science audiences.
- Achieving greater breadth of understanding about the context surrounding research. While research itself may have a narrow focus, presenting requires greater breadth because the audience will want to know how to locate the research within the broader fields of knowledge.

  Presenting helps you learn more beyond what you are doing; you have to do a lot of reading to understand the science behind your work. And the contact with other scientists strengthens your knowledge.
- Discussion and networking with faculty and students.

  You wonder what people will ask, so you ask yourself a lot of questions about what you might be asked. And you meet new people and get new ideas.
- Learning about a wide variety of research, in many different areas. As they present their research, the MARC fellows review the presentations of their peers.

  I really enjoyed seeing the diversity and the quality from so many different departments on campus.

Mentors and the Mentoring Process As in past years, the MARC students discussed benefits of their interactions with research mentors. All of those interviewed reported that their research mentors or the graduate students with whom they worked were available to guide and assist them. Several of these students expressed pride in their independent work while admitting that they also liked the security of having someone nearby, to provide direction.

- *If I have questions there is always someone I can go to. It is good to have support. He is around and I feel more comfortable when he is around. But I like working independently.*
- *I worked with a grad student; and then started to work more independently. What I am doing now is a project that no one else is doing. So if I get stuck I have to read and read. I feel it has taken more time. I would go faster with a graduate student. But I get a sense of what doing graduate-level research is like; having to do it for myself.*

<u>The Future</u> All of the MARC students who were interviewed said they intended to pursue graduate studies; most indicated that they were interested in the MD/PhD degree. One had been accepted into a PhD program; one was intending to apply for a post-baccalaureate research program, and then go on to a Ph.D. program. They felt that the guidance they were receiving from their mentors and MARC personnel was helpful.

> *I don't have to apply to grad schools this year and my mentor has been helpful in figuring out what schools and departments I should apply to.*

<u>Summary</u> The MARC fellows were enthusiastic about the program and about their research. While the MD/PhD is an important degree and one that opens doors to careers that span research and clinical work, it is unusual in our experience for such a large portion of fellows to be looking in this direction. It might be useful to hold more seminars on the life and world of academics, the pursuit of research, and the varied opportunities in this area. Stony Brook has a number of scientists who would be informative and motivational in this regard.

Undergraduate Research Fellowships The benefits of research to undergraduates have been thoroughly documented (Gafney, 2001; Lopatto, 2007; Seymour et al., 2004;). In brief, students begin to do science rather than simply learn about it. They also gain a deeper understanding of themselves, their ability to persevere in the face of challenges, and their taste for science. Recognizing these and other benefits, and drawing on experiences with the MARC program, CESAME has used HHMI resources to fund research fellowships for undergraduates beginning with the first grant in 1994 and continuing to the present.

Over the years, CESAME has awarded 225 undergraduate research fellowships. The recipients have been academically productive, co-authoring more than 140 papers and abstracts. Fifty-eight percent of the fellows have been women and 18% were from underrepresented minority populations. Of those who have graduated, 97% received a bachelor's degree in a STEM field, 30% are in PhD programs or have received their doctoral degree. More than 100 faculty members from 20 different departments have mentored these students. In some years these fellowships and the related outcomes were evaluated more fully than in others. The following is from one such HHMI evaluation.

Interviews were conducted with Howard Hughes fellows and mentors. Students were asked about: their initial understanding of research; how the learning of science in research differs from classroom learning; the mentoring relationship; and career interests. Mentors were asked about the mentoring relationship; how they guided undergraduates; the kinds of contributions undergraduates could make to research; and the aspirations regarding graduate studies and careers that they observed in their students.

In a number of years, the evaluations paid particular attention to students' initial impressions of research, adjustments to mentors, and ways in which research impacts students' motivation toward graduate school, medical school, and other careers. While not neglecting these areas, the evaluation for the year in question focused on how students view the differences between classroom learning and the learning that takes place in research.

Students were also asked what advice they would give others who were just starting to do research as undergraduates. This activity revealed that students were reflective and had developed an understanding of the challenges that accompany research.

Students were articulate in discussing what they perceive as major differences between class work and research, as follows.

Characteristics of classroom learning:

- You are fed information.
- You retain what you learn for the test. *When you learn in the classroom you are learning for the test, so that adds stress. When you are learning in the lab, you are learning because you want to.*
- *You are forced to do it.*
- *It is from a textbook. You never see how the formulas are really applied.*
- *You don't generally see what it means in the "real world."*

Characteristics of research activities and related learning:

- *When you are working in the lab you are allowed to be more of a free thinker using your own ideas.*
- *There is not so much stress.*
- *You are always reinforcing what you have learned, through repetition and discussion.*
- *It doesn't seem like work; it's something you love to do.*
- *You learn that science is always changing. We came up with something that we didn't expect and there were four different interpretations about what it might mean.*
- *You learn from background literature and also from doing.*
- *You feel that what you are doing is real. You don't know where the answer will come from.*

When asked what advice they would give other students starting research, the students listed the following.

- *Do something you really like.*
- *Persistence is important. Just because an experiment works once doesn't mean it will keep working. Sometimes you can do something with the exact same conditions and it will refuse to work;*
- *Attention to detail is important; you have to record everything you do; it's very important if you change the conditions;*
- *You should have people review your work;*

- *Teamwork and independence are both important. You do your own work but everyone compares results, to find the best way; Plan and be alert to the unexpected.*

Biology High School Summer Workshops The BioPrep research program for community college students and the Biology Teaching Labs led naturally to a program of summer research for high school students. At different times in past years, there have been one or two programs in which high school students spend four weeks at Stony Brook, first learning laboratory techniques in biology, and then pursuing team-based research projects. One of these programs was funded by HHMI and invited minority students from area high schools to participate. Another program was similar but fee-based and open to applicants who wished to pay. Particular attention was given to evaluation of the program for minority students.

Between 1998 and 2010, 210 students, 71% of those attending the HHMI-sponsored residential High School Scholars Program were from underrepresented populations. As of 2010, 73% of the program's graduating seniors matriculated to college; 48% of the students had received bachelor's degrees; and 13 of these students had received doctoral degrees. Approximately 25% of these students enrolled at Stony Brook.

The following from one of the evaluation reports, describes some of the issues and benefits from the program.

Background As part of this year's evaluation, 22 of the participating students were interviewed in five small groups. The instructors were also interviewed. The students were animated in discussing the program and they identified a number of particular benefits and experiences.

Research When asked what they had learned about research, students made a number of comments that their instructors and other researchers would undoubtedly agree with. These included:

- *It doesn't always work out.* (One Stony Brook researcher said they are lucky if experiments are successful 5% of the time.)
- *Research is hard work.*
- *You have to be very careful; contamination is always an issue.*
- *You have to read about what you want to do, to learn what other scientists have done.*

Faculty The students were enthusiastic about the faculty, saying that having different presenters and teachers available to respond to questions was very helpful. They liked the fact that background learning and lab were closely connected, saying that in high school several days often elapsed between class and the related lab experiment. Students found the program faculty to be clear in presenting science, personally accessible, and always friendly.

Projects Students select their research projects, but program staff pointed out the challenges involved in identifying projects that will:

- Make use of the skills and knowledge acquired in the first part of the program;
- Be doable within the timeframe and with the available materials;
- Challenge students but also have the promise of achieving outcomes that are interesting and can be presented.

In spite of these significant issues, students working with the program faculty did identify small group projects that exercised the skills acquired in the program and in which they could achieve results within the constraints of time and skills required. Students were articulate in describing their projects and in the efforts they were making to produce posters that would describe what they had done, the questions they were addressing, and what they had achieved. The development of presentation skills remains a significant part of the program.

Tensions in the Teaching/Learning Environment The discussions with this year's participants and staff led to consideration of several tensions or even paradoxes that appear in a productive research learning environment.

A Structured but Open Environment It is a commonplace in education that students need an orderly, predictable structure in which to learn, but they want room in which to exercise a level of independence, making decisions and choices about their learning. Teachers often take one of these as their default position: insisting on rigid uniformity in teaching and learning or leaving so much to the students that the atmosphere becomes chaotic. The Howard Hughes summer program achieves an excellent balance in teaching a structured set of skills, while providing a moderately open atmosphere in which students form groups, pursue projects, and plan their reports.

Work That is Difficult but Enjoyable When asked to compare the summer program with their high school studies, students said that the work they did at Stony Brook was more demanding than at school. They also said it was more enjoyable. When it was pointed out that hard work and enjoyment can thus be found in the same activity, they readily acknowledged that this was the case. Many students, not engaged in programs like this one, think that hard work means drudgery; release from work means a time for fun and enjoyment. These students have found something that if it endures will be of great value in their on-going education, namely that difficult and challenging work can be very satisfying.

Teachers Who Are Knowledgeable but Admit not Knowing Students reported that the teachers in the program "knew a lot." The confidence and professionalism of the staff seems to have been evident through all of the program's activities. This very confidence permitted teachers to answer questions with a question, and to admit when they had to look something up. Students found this refreshing and wanted to imitate these qualities, striving to learn thoroughly but also to be inquisitive, able to listen to others, and to admit mistakes.

In summary, both the quantitative data and student comments indicate that the summer research programs provided high school students with experiences doing science and understanding themselves in new ways. They became realistically motivated to work hard in college science, and beyond.

4. Development and Implementation of Innovative Courses, Collaboration and On-Campus Partnerships

Innovative Courses The outreach science activities initiated by CESAME with grant funding provided a strong start and opened doors to the educational world beyond Stony Brook. But a university is built on departments and courses. Recognizing this, Bynum utilized the second HHMI grant to support the development of innovative courses and continued this development with subsequent grants. Courses were generally initiated because of a special innovative interest of the professor, and needs that were not being met within the departments. The following are the courses that were sponsored by CESAME during the 2013-14 academic year. We are not listing courses offered in the MAT and Ph.D. programs; nor are we listing courses that are jointly taught by CESAME and departments as part of the core biology curriculum. Courses in both of these areas are discussed in other parts of this report. The courses listed below are generally special interest electives.

Undergraduate Courses

BIO 311: Techniques in Molecular and Cell Biology

BIO 312: Introduction to Bioinformatics (Dept. Ecology & Evolution)

BIO 314: Cancer Biology (Dept. Biochemistry & Cell Biology)

BIO 318: Bioethics and Policy

BIO 364: Cancer Biology Laboratory

BIO 367: Laboratory Molecular Diversity (Dept. Ecology & Evolution)

Graduate Courses

BIO 558: Biology and Human Behavior

CEB 554: Current Topics in Immunology

CEB 557: Forensic Science

The following paragraphs are from an evaluation of courses that was conducted in 2009. The evaluation considered four of the six undergraduate courses listed above, and one that is not listed for 2013. Interviews were conducted with professors for five courses. These interviews were semi-structured, with a common format but ample room for discussion appropriate to each course, as well as a review of issues, challenges, and outcomes.

The more important areas discussed were:

- Course content. Under this heading we reviewed the main topics in the course, and how they differed from more traditional courses.
- Teaching/learning strategies and activities. The activities that engaged the instructors and students in these courses were more student-centered, project-based and current than in most of the other courses.
- Impact of biology on society. This theme was present in all of the courses with considerations of the ways in which biology is related to areas such as public health, ecology, energy, and ethics.

Faculty members who are affiliated with CESAME taught four of the five courses under discussion. They were in frequent contact with one another, exchanging ideas and materials about effective teaching and learning. These interactions create an informal basis for one of the best approaches to professional development and growth—shared experiences and reflections about what strategies have been most effective in bringing science to life for today's students.

Professors who were interviewed were also asked for samples of course materials. These were subsequently reviewed for content and method. In recent years there have been a variety of pedagogical initiatives promoting more active learning in college science courses. (These include Conceptests, Peer-Led Team Learning, Peer-Oriented Guided Inquiry, Problem-Based Learning, and more.) The methods under discussion participate in this movement to improve pedagogy, with engaging in-class activities along with demanding out-of-class preparation and follow-up.

Result of Assessment The following table provides the titles, content and method for the five courses with indications of the experiential nature of the courses.

Courses	***Content: Impact of Biology on Society***	***Method: Active, Team-based, Exploratory; Continuous Updating of Materials***
Introduction to Biotechnology	For non-majors, covers current issues in theory and practice, e.g. forensic evidence	Debates, presentations, lab activities covering basic practices, such as DNA
Techniques in Molecular and Cellular Biology	Research methods needed for advanced courses and graduate school.	Lecture, with lab sections of 20 students each; includes TA and MAT training.
Cancer Biology	Investigates the impact of cancer on molecular and cellular activities.	Exploration of research with implications explained by a long-time researcher.
Molecular Immunology	Current theory and practice related to the immune system.	Explorations of how anti-bodies target intruders; recent literature on immunology.
Bioethics and Policy	Issues and topics: assumptions and proof; issues in health care and insurance; FDA regulations; gene therapy.	Debates in each class, with careful preparation and guidance by the professor; readings on current issues

In these HHMI-sponsored courses, students developed and used analytical skills in the study of biological issues in contemporary society. Issues such as the common assumptions and evidence used in setting standards and issuing guidelines for health, the role of the FDA in testing and approving substances, are sometimes mentioned in courses but not carefully analyzed. These and similar topics are nevertheless important factors when biology enters the public arena.

The Introduction to Biology course teaches the laboratory methods of DNA analysis; then in debate and discussion, students discuss the value and uses of forensic evidence. In the Immunology course, students study the reasons why the geometric shape of certain antibody molecules makes them efficient in their protective work, targeting potentially dangerous invaders. In these and the other CESAME-sponsored courses, students focus on topics that are often on the periphery of the biology curriculum, but hold an important place in public discussions.

Based on interviews and observations, there is considerable evidence that students taking these courses emerge with a deeper understanding of the impact of science on society, particularly in areas of health and the environment. The participating students acquired skills in analyzing scientific data and reasoning. They also developed the confidence required to participate intelligently in discussions about science and public policy. They will, in short, become part of the scientifically literate population needed in the coming years.

<u>Mentored Teaching</u> The evaluation for 2012 included student interviews with those who had obtained fellowships and were engaged in mentored or collaborative teaching. Interviews confirmed what common sense as well as the literature has suggested regarding benefits to be gained from these practices, namely:

- The teaching fellow gains both knowledge and the opportunity to try new approaches while working with a more experienced individual or faculty team;
- The pair or group are able to build on successful strategies and try new approaches to teaching and learning;
- Knowledge is gained about how students learn, as well as about incentives and obstacles to learning.

Interviews provided a number of examples of this learning and development. A post-doctoral fellow working collaboratively with several faculty members on a lab-based course in cancer research discussed the multiple benefits and advantages embedded in the approach.

> *Experiments never go the way you plan. The timing is not ideal; it's too short. … I loved interacting with the students. I think they had a good experience. They saw how things go in a real lab. In the first half we taught them the techniques. Then they took on independent projects, in groups. I think they grasped the information, and were able to apply it pretty well. … They also replicated some research that they read about in journals.*

The quote describes a situation in which the fellow was: learning from challenging situations; combining lab work with appropriate theory; guiding group projects; and informally assessing student engagement.

Another fellow discussed the academic progress of students she was teaching, connecting it with learning situations and motivation. The availability of lecture, lab, and support materials electronically appears to have been important, but there was still a noticeable difference among students, based on attendance at classes. Those who attended regularly were more engaged in the review sessions and achieved higher grades.

> *The review sessions were very useful to the students; we told them what ideas were more important. You could tell from their responses who had come to the lectures. We also made the lecture material available on audio and pdf files. I put links on the slides.*

Curriculum Development and Materials Most of the mentored-fellows who were interviewed talked about their work preparing materials and developing a curriculum for the course or program of studies in which they were participating. The student working with the cancer research course, mentioned above, said that she prepared experiments and wrote parts of a lab manual.

A fellow working as a post-doctoral fellow at Brookhaven National Lab talked about the importance of preparing a curriculum that will extend the impact of the project beyond the time of the his involvement.

> *It is good to teach but better to develop curriculum, and programs. But being in the classroom helped me understand what the kids could and could not do. … Some of the*

high school students are very advanced. A lot of them seem really excited. I also taught a few lesson labs to middle school students. They got very excited about how these things work in the cell.

Research The fellows, funded by the grants, are engaged in research as well as educational work. Several of them discussed how the research they were doing built on and extending their doctoral research.

One of the fellows, who is enrolled in the PhD in science education program, plans to do a dissertation examining the interaction and impact of mathematics on science learning at the middle school level, and the study has provided the basis for an article (in press). She noted that there is a good deal of theoretical literature, but little experimental data, "showing whether it is effective."

Professional Development and Career Preparation All of the teaching fellows who were interviewed believed that the educational experiences gained though the HHMI fellowship would deepen their understanding of teaching and strengthen their ability to secure a faculty position in the future. The fellowships combine research, scholarship, and educational practices in ways that benefit the individual and the institution, while creating new methods and models in science education.

On-Campus Collaborative Events Over the years, Bynum has pursued whatever opportunities arose in exploratory, innovative, and problem-solving approaches to science and mathematics. The result of these collaborative efforts at Stony Brook in some cases have been self-supporting annual events. We have reviewed and evaluated three of these and present the results here.

<u>URECA (Undergraduate Research and Creative Activities)</u> The URECA program, as the name implies, encourages research, exploration, and creativity across the disciplines. The URECA and CESAME websites describe the connections between the two. Research fellowships funded and mentored through CESAME programs often conclude with projects at the URECA competition. Those interested in research, during the academic year or summer, are referred to several of the programs sponsored and funded by CESAME. The history and growth of URECA stem in part from and NSF RAIRE (Recognition Award for the Integration of Research and Education) grant that led to the first URECA celebration in 1999.

The program for the annual celebration held in April, 2013, listed 268 poster, 21 oral presentations, and exhibits of student art. The impression, based on observations and brief interviews, was one of extraordinary energy and student satisfaction in their achievements. The abstracts, made available on disk with the program booklet and index, lists projects in more than 40 disciplines. The abstracts themselves are generally well written and provide a good overview of the activities and learning gained from the program.

Interviews at Student Posters While observing the posters, artifacts, and inventions, the evaluation engaged in casual interviews. The following are taken from these interviews.

Remote Sensing. *We are using a model for the scattering of light; we have programs to do the math. A lot of people just use an estimated n value; this will give them a more accurate mathematical value. But it is not experimental. The process (in the project) is used in remote sensing.*

What did you learn about yourself? *I had always questioned whether I had the stomach for research and how I would handle graduate school. But now I feel I can do it. I'm glad I got this*

project because it takes enough mental power and might be like what I would have to do in graduate school. We received a stipend during the summer; but we do it for credit during the year.
Stem Cells. *You need stem cells; … So we mimic what happens and we inject … into the cortex of the mice. And you can see the results; and where we injected, it is broken; where we did not inject, it is not broken.*
How will it affect your future? *I never did any neuroscience but now I am very engaged in it. … He paired me up with a grad student*
How much time did you spend? *A lot; 15 or more hours a week.*
Psychology Project on Undergraduates. *I am at the career center.* [Showing data on her poster.] *These are incoming freshmen, they were given surveys; this part analyzes gender differences; females tend to have more family connections, but they are also more positive and self-motivated; males tend to be more enterprising and investigative; women are more social, relationship-oriented. But they are more anxious about their career directions. We did open-ended interviews. The females talked more about courses and internships; the males (said they) worked out, hung around. Girls call home a lot; boys not so much. … I am going to work at the career center; and do graduate program in college administration.*
Sociology Subcultures. *We studied sociology subcultures. We wanted to find out which factors led students to participate in a sub-group of their own ethnicity. We used a survey; we found that as pride in ethnicity increases, they are more likely to be in such a group. As enthusiasm for the major increases, segregation into an ethnic group decreases. "You can be friends with someone based more on the major." Majors such as chemistry and biology had the highest level of segregation. Hispanics had a high level of integration; we were happy to replicate this. … I am a philosophy major; as an undergraduate, it is helpful to learn things that are useful to all of us. Our mentors guided us; we did the work. What sort of identity do people have when they come to SBU; so we were interested in identity formation and development. … This needs a lot more study; it is the first*
Did it change your thinking about your future? *It may not have changed my career path, but it changed my thinking about this university. I have gotten to see how people split apart. … The project treated lot of the basic tenets of social science research; so we got to see a lot of what goes on in social science research; but it was about our own world; so we got to step outside and understand it better.*
<u>Protein Competition</u> Joan Kiely of CESAME has administered the protein modeling competition for the past four years. The competition, funded in part by HHMI and also supported by pharmaceutical companies, brings together students from a number of Long Island high schools. There are several parts to the program.

- Each school sponsors a team; three students come to the competition, but others may participate in preparing the model. About 30 teams participated in the 2012 competition.
- Schools are given the name and specifications of the protein. For 2012, the protein was related to the spread of cancer. In preparation for the day of the competition, teams prepare a model of the protein. Although all worked on the same model, the teams showed imagination in adding details related to the activity of the protein. On the day of the competition, the teams set up their models and then take a team-based test. The

test includes items asking for basic information and the teams are given instructions that are used to construct another model. The models are rated using a 14-item, 30-point rubric. And the tests are also scored.

- Lunch is provided and awards are made based on the models, test, and additional models constructed at the event.

Observations and Interviews Teachers and students were briefly interviewed. They were highly enthusiastic about the program, with comments in the following areas.

- One teacher said that the program was not limited to more advanced students, rather. "It took every student to a new level." Some students with knowledge limited to textbook learning, commented about proteins with surprise, 'They (proteins) really exist.' The more advanced students were pleased to find that what they were learning in school had practical applications.
- The teams are provided with a journal article related to the protein and other materials in preparation for the event.
- One team provided an imaginative, miniature museum setting with the protein as a central exhibit surrounded by paintings on the wall and other explanatory materials. Another showed a baby and described the activity of the protein in embryonic development. A third showed the activity of the protein in a cancerous squirrel.
- Students related the project to their levels in school, one noting that since she had not taken an advanced placement course she did not know about protein structure and behavior, but the project got her started.
- Several students said they wished they did more projects of this kind in school; that building a model helped them learn and remember the structure and function. One commented, "I am a very visual learner."
- Members of the pharmaceutical company who served as judges commented on the variety and creativity of the models, saying that, 'they got it right,' and also expanded on the requirements.
- Undergraduate students who also served as judges said that many people think proteins are magical. "But there is a biological and chemical structure that explains everything they do."
- All of those involved thought that the teamwork was productive, leading to expanded results, and allowing students to specialize. Some, for example, were more capable with computers; others in building models; others in the theoretical areas.

Networking In addition to the knowledge and experience gained, the activity introduced students to methods of inquiry, exercises in presentation, and the cooperation that science fosters. They and their teachers interacted with researchers from drug companies, as well as college professors and students. They met students from other schools, and visited the Stony Brook campus.

In addition to the benefits identified above, the program demonstrates and expands the reach of CESAME. One of the participating teachers was a graduate of the master's in science teaching program; another taught in the summer professional development workshops; and all learned more about the resources available at the university.

Improvements The program director reported that a number of changes and improvements had been introduced to the program this year. With the loan of computers from Stony Brook, they were able to have all of the student contestants do the protein modeling during the first hour. This gave the judges more time to review the students' work. In this way the judges finished earlier and joined the students for lunch.

Participation by the pharmaceutical company scientists has expanded over the years. They reported a great deal of satisfaction in their contribution and said that they were impressed with the skills, imagination, and industry exhibited by the students.

Math Competition For several years CESAME has collaborated with a number of school districts on Long Island to sponsor a mathematics competition in the spring of each year. For each of the past few years more than 200 students have participated. They practice at their schools, both individually and as teams. The competition starts with individual problem solving. The students then gather for a review of the problems and have an opportunity to offer their solutions. After this they meet as teams and are given a set of problems to solve.

In solutions to problems for the individual competition, the students demonstrated a solid knowledge of number facts, a basic understanding of mathematical concepts appropriate to their age and level in school, and facility with problem solving strategies, particularly trial and revision. In general the material covered the skills and concepts that are considered as pre-algebra and the students appeared to be ready for algebra—not only in skills but also in conceptual understanding. They were articulate in explaining the logic behind their thinking and the solutions that emerged. For example, part of a problem described a number as "one less than a number divisible by five," and the student proposing a solution said that, "the number had to end in nine or four." They used other strategies as needed—particularly tables to sort information. One teacher noted that in recent years the curriculum has placed an increased emphasis on explaining solutions and "kids are getting better at it."

Teachers made interesting comments about the event and its benefits.

- *The important thing is not winning; it is just the doing. We came to have fun.*
- *In doing the project we train the kids to work as a team. You have five brains working.*
- *It shows the kids that they can excel. … there aren't many all-day academic experiences like this.*
- *There are a lot of dedicated teachers involved.*
- *It's healthy competition; lets them see how they can do against the rest of the kids in Suffolk County.*
- *The social aspect gets girls involved.*

Students were enthusiastic—in offering solutions to the individual competition, in discussions with their teachers between events, and in working on the team problems. This kind of excitement is rarely seen in mathematics classes. Teachers said that they meet regularly with the students in after-school sessions or clubs. In these meetings they practice solving problems and eventually narrow down the students to select those who will be on the teams for the competition. Some schools bring more than one team. A teacher was overheard telling her students to read over the group problems and then each student on the team was to work on a problem that he or she was able to solve. They would then discuss solutions and work together on the more difficult problems.

5 Biology Curriculum Revisions and Educational Research

As previously mentioned, CESAME has its roots in teaching and providing research opportunities in biology. Bynum's home department is Biochemistry and Cell Biology. In addition, the earliest outreach activities and HHMI grants focused on biology with the teaching lab and curricular improvement at Stony Brook. In the past few years the biology focus and activities have led to an increased emphasis on educational research.

Biology Curricular Revisions In the academic year, 2007-08, the introductory biology curriculum was revised, with strong support from HHMI funding through CESAME. Improvements have been made continually since that time so that the current structure contains the following features, which will be discussed at greater length below.

- Students are required to take three 3-credit, lecture-based courses. These courses are not connected and may be taken in any order; they are: BIO 201 Organisms and Ecosystems; BIO 202 Molecular and Cellular Biology; BIO 203 Cellular and Organ Physiology.
- Students are also required to take two 2-credit lab courses. These courses develop skills, concepts, and procedures, independently of the lecture courses, and are important prerequisites for upper-level courses. The labs are taken in sequence: BIO 204 and BIO 205, Fundamentals of Scientific Inquiry in the Biological Sciences I and II.
- There is a lab course, BIO 207, that is an alternative to the BIO 205 lab course and contains a number of special features.
- The lab courses contain lecture components and these are available on podcast, to be watched before the class. In an average year there are more than 40 lab sections, and so efforts have been made to include some uniformity among the sections while also encouraging individual and group explorations.
- Activities have been piloted in the training of teaching assistants. These include the use of improvisational workshops, with training from the Alan Alda Center for Communicating Science.
- The joint appointment of a tenured faculty member, Ross Nehm, to CESAME and the Department of Ecology and Evolution has created stronger ties between the two groups and has introduced rigorous educational research into certain areas of the introductory curriculum.

With the revision of the introductory courses and labs, HHMI funding was particularly important in the modernization of labs, and the purchase of a 3D printer to construct molecular models. As early as 2008, the program began using elements of what is now called the flip model, namely that students were expected to study and become familiar with material before classes which would be used for further exploration, applications, problem solving, and the like, in class. Professionally developed podcasts were provided to explain the background and to demonstrate the skills required labs. Using these resources, students became well prepared for the lab activities.

In developing curriculum, preparing new materials, and devising teaching/learning activities, those working on the introductory program subscribe to the tenets of Jo Handelsman and the Scientific Teaching she has championed. As described by Peter Gergen, the essentials of the method are: (1) to pursue active learning that goes beyond lecture; (2) to maintain constant assessment, considering where students are in their learning, including what they know and what they don't know; (3) to have learning objectives with outcomes identified; and (4) to consider diversity of backgrounds and needs among students.

Improved Pedagogy A professor, John True, who had been teaching one of the introductory biology courses for eight years, sometimes in partnership with a colleague, discussed how teaming with a CESAME faculty member, Ross Nehm, with experience in educational research has made a big difference in the course. He described the planning and how he viewed the changes.

> *This is an important part of his (Nehm) work here; he can contribute to and modernize the program; it's also an opportunity for me to learn about the science of teaching biology. We met all summer and redesigned the course. It's still a work in progress.*

Further in the interview he discussed the use of clickers. These are now fairly common in large introductory classes but, as he explained, there are important differences in whether they are used for quick memory checks, or for more thoughtful responses. This activity reflects the work of Eric Mazur of Harvard who pioneered the use of Conceptests, with brief paired discussions, in having students think and talk, particularly about conceptual learning.

> *We developed POE—predict, observe, explain questions. You present a situation where something is going to happen, maybe on a video. Have them make a prediction, watch, and explain. One class has 400; another class drew about 200. We tell them, "Talk to the person next to you." Some faculty members are doing the same thing in chemistry and physics.*

Devising clicker questions sounds easy when described. But two HHMI-funded graduate students spent a summer writing them. They had given a lot of thought to the process and were articulate in explaining what they were about. In addition to, or along with, the clicker questions they developed activities, "challenging students' preconceptions." They gave an example of an interesting clicker/preconception item for ecology/evolution course.

They said that the majority answered correctly, but that 20% wrong is "a pretty big misconception," so there was an opportunity to teach and reinforce an important concept in evolution. The graduate students felt that developing the misconception questions and observing classes had taught them a great deal about teaching and learning.

> *You can't assume that they understand the words. They use them in ways that are right enough. But because they can use a word does not mean they really understand it.*
>
> *We want all the students to apply knowledge to new situations, but they need the bridges. … A lot of the effort is to get students to feel good about themselves.*

The teaching assistants creating the items went on to express their admiration for the faculty member teaching the course and others who were developing and using new methods of teaching and encouraging more exploratory learning.

When the professor in question was asked about CESAME's contribution, he described the importance of expertise in teaching.

> *It (CESAME) has been critical and is becoming more so; to have people like Ross and Keith. We are scientists; our main job is to do our research. But we are paid to teach. So there is a tension; most of us don't know much about teaching. And we don't have time to slow down and retool our course. But now that we have this brain trust we can do it with a lot of courses; it will help with the online course we have during the summer; we*

have worked with some ok videos but we will have more; and eventually may have a flip system. Ross knows the methodology to assess whether these things are working. A scientist may think he knows; but Ross really knows the standards.

New Approaches to Biology Labs A graduate student, Niamh O'Hara, working with a faculty member, Marvin O'Neal, drafted new curriculum materials for the alternative introductory lab course, mentioned above. The lessons provide excellent introductions, called Scientific Inquiry, that are both motivational and informative. One lab begins with questions about annual flu vaccinations, pointing out that the need is based on evolution, "the unifying principle of all biology," and on the constant evolution of viruses. The section concludes with the statement that in this lab, "you will witness evolution occurring in just one week."

The materials continue with pre-lab assignments that contain: scientific and historic background; illustrations, for example of the Lyme disease cycle; protocols; a format for stating hypotheses; methods to see whether evolution occurred; and questions for analysis and conclusions. The labs appeared to very carefully directed but open enough to require real investigation.

A second important element of the lab courses is reading scientific papers, with student reports. To manage the system—with 24 students in each of 40 sections—24 different papers are selected. Each student in a section receives a different paper, and all 40 reports on the same paper are read and assessed by one faculty member. After reading the paper, students watch a podcast of an interview with the author. Learning based on reading the papers and watching the podcasts is being assessed to determine which are the more effective teaching/learning activities and how they can be best used cooperatively. Those working on the course are assessing student learning outcomes and comparing them with control groups.

Training Teaching Assistants Stony Brook requires that all graduate students work as teaching assistants at some time during their studies. But the duties and activities of teaching assistants vary greatly depending on the discipline and course. These activities include: assisting with labs, working with recitation sections, grading papers, co-teaching with a faculty member, preparing curriculum and materials, etc.

With regard to the changes in biology, one of the professors said that making changes in the work of the teaching assistants was the most challenging. In this regard, probably the most interesting and unusual activity, and one supported by CESAME, is the use of improvisational theater techniques in training. The project came about because Alan Alda has a serious interest in science education in the broadest sense, and he also has a connection with Stony Brook. He has funded the Alan Alda Center for Communicating Science. He also noted that improvisation was the most important activity in his training to become an actor, and suggested its use in training teachers. Thus was born the idea of using improvisation as part of the training for teaching assistants working with the biology labs discussed above.

Two graduate students in biology were awarded CESAME (HHMI) fellowships to monitor and evaluate the improvisation project. They were interviewed several times. And materials from the project were reviewed. Goals of the project were to improve the skills of the teaching assistants, to make them more comfortable in their contacts with students, and to improve the academic performance of students. The study included eight teaching assistants who participated in the improvisation workshops and eight who did not. The improvisation students

learned and practiced techniques such as spending extra time with a reluctant student. They reported success with this and other strategies.
Preliminary findings are positive in all areas. After some initial complaints that they were being asked to do more than others, the improvisation group provided positive feedback, finding satisfaction with their students. Student ratings of the assistants in the improvisation group were generally higher than those of the control group. The fellows conducting the research said they received a very positive reception when presenting at a conference on teaching biology.

Pedagogy in Other Science Departments Another faculty member, Angela Kelly, hired jointly by CESAME and the physics department has had a positive impact. She has experience as a high school teacher and was engaged for a number of years doing in-service training with teachers. At Stony Brook she has had the highest student ratings for introductory physics courses, in many years. She attributes her success to her high school experience and the ability to assess formatively whether students understand; and if not, to try another approach, introducing exploratory methods and applications. She said they hope to pilot an MIT model that combines lecture, lab, and recitation, with students seated tables. Her classes have 200 to 250 students.

In Chemistry, David Hanson and Troy Wolfskill have incorporated a number of exploratory pedagogies into the introductory chemistry courses. They and others from Stony Brook have participated in a number of national activities for the improvement of curriculum, teaching, and learning. The university supports a task force on science education and has hosted summer workshops on pedagogy. But these are only indirectly related to CESAME and take us beyond the purposes of this report.

6 CESAME: Graduate Programs in Science and Mathematics Teaching; Fostering Leadership; and Professional Development

CESAME, as a center for teaching and learning has evolved in response to opportunities, with expanding resources, and planning based on educational needs. The Center started with biology because that is where Dr. Bynum was situated. Major grants were obtained. But in a short time it became clear that the successes in biology were transferable to the other sciences and to mathematics. Working with underrepresented minority and at-risk students was both a national need and an area of concern for Dr. Bynum. Similarly, there were educational studies pointing to the benefits of active learning at all levels and these became a priority in CESAME's programs and grants. So what can appear to be serendipitous growth was also an organic evolution, as the organization grew and adapted. Some activities that emerged later seemed to be the most significant as the organization moved forward.

Ph.D. Program in Science Education The Ph.D. Program in Science Education at Stony Brook is well balanced, including: strategies for teaching and learning science; the history and best practices in science education; curriculum development and assessment; topics in science teacher education; societal issues; and specialization in at least one of the sciences. Students also take courses in statistics and research methods, must pass qualifying exams, and complete the dissertation process that includes: proposal, oral exam, research, and writing.

The program started with the 2010-11 academic year. A second cohort was admitted in the following year. With the expansion of the program and new hiring, no students were accepted in the 2012-13 academic year; but a third cohort was accepted for the 2013-14 academic year. The cohorts contain 10 to 12 students each; all of the students are employed while pursuing their degrees. The student participants of the first cohort were mature, with 10 to 20 years of experiences in schools. The students of the first two cohorts have come from varied work environments, including: high school and middle school teaching: departmental administration; college teaching; and teaching in the CESAME MAT programs at Stony Brook. The program adds to and builds on the resources and activities of the Center. This review of the program is based on: conversations with the program faculty, interviews and focus group sessions with the students, several class observations; and a review of program literature.

Structure and Staff Dr. Sheppard, the program director, drawing on his experience designing a similar program at Columbia University and has incorporated the following program features:

- A depth and breadth component. Participants are required to take courses across the science education spectrum and are also expected to become deeply immersed and proficient in a particular area. The program also provides a rich historical context based in part on one of the research areas of the director (Sheppard & Gunning, in press).
- A qualifying exam/paper that looks both back and forward. Students will demonstrate a comprehensive understanding of the various elements of science education as well as evidence of research skills and the focus needed to proceed with a dissertation project.
- An individualized program, tailored to each participant's experiences, needs, and plans. The courses and related activities contain: exploratory and research components; historical and international components, considering education as it has developed and

as it is practiced in various settings; teamwork and collegial activities; and whatever special activities are most suitable to the individual.

- The expectation that those completing the degree will generally move toward one of three career tracks: as heads of school science departments or district curriculum administrators; as college faculty in science education, working with teachers, future teachers, and science specialists; and as researchers in science education.

In addition to Dr. Sheppard, three faculty members have been hired for the program and each holds a joint appointment with the PhD program and a Stony Brook department. The doctoral program, therefore, while holding its own position within CESAME and the university is also closely connected to the academic environment at the university.

Dr. Angela Kelly holds joint positions as associate director of the doctoral program and with the Stony Brook Department of Physics and Astronomy. As this hire demonstrates, the program seeks faculty members who over the years have demonstrated a serious interest in exploratory learning with grants that have recognized and supported their educational work. Dr. Kelly has extensive experience with secondary school science. After the first round of student comments on her course, a senior colleague said he had never seen such enthusiastic student reviews for an introductory course.

Ross Nehm, another hire, holds joint appointments with CESAME and the Department of Evolution and Ecology. He has done nationally recognized research work in the teaching and learning of evolution. At Stony Brook he is co-teaching one of the introductory biology course, and his co-teacher who has had more than 10 years experience teaching the course said that Dr. Nehm has helped him realize that there are alternatives to the traditional "weed out" approach to introductory courses.

First Cohort: Spring, 2011 (Based on interviews with Cohort 1 students and a class observation, April 2011) Members of the first cohort generally agreed that the PhD program is well organized and engaging. At the time of the visit, the participants were in their second course, both taught by Dr. Sheppard. They felt they were pioneers, but also that they had a very useful set of guidelines to help them with decisions and planning. They also appreciated the mentoring and guidance from Dr. Sheppard

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We are clear about courses needed; when to take them; and the timeline. We know where we are going to be next year and after that; what the benchmarks are; and how to fulfill the breadth and depth requirements.

The required courses offer a good introduction to the program; and the group has developed a personality. Friendships have developed. So we feel we are part of a community. This is very important because the program has no history; we are writing it. Everyone has a different perspective.

The participants were generally optimistic and confident about their futures in the program, although some admitted their anxiety about future courses and dissertations. But they also reported that the director appreciated their concerns and encouraged them to work at a comfortable pace.

- *At first I was overwhelmed, but the pieces are falling into place and I don't feel stressed about it.*

- *It will be important to find the right professor; for example I don't want an advanced mathematical approach to statistics.*
- *Keith is very supportive. He tells us to pace ourselves; to satisfy all the requirements, and not to take on too much. … He told me not to take anything during the summer and that made me very happy.*

The participants (PhD candidates) commented that, unlike many of their contemporaries at the schools where they teach, they had a positive and reasonably optimistic view of education, although they were not blind to its many deficiencies. One of the teacher-participants, in a class that was observed, discussed activities in her district that focused on efforts to address diversity, parental concerns, and motivation regarding the role of the honor's curriculum. The class discussion covered:

- Issues surrounding heterogeneous and homogeneous groupings of students;
- Assessment of student performance and grading;
- Satisfying prerequisites for future schooling;
- Balancing an interest in student motivation with realistic requirements;

In some ways the district's approach illustrated the cyclic pattern described earlier in this report. It may be that some decision makers in American education lack clarity about what needs to be done or they lack the confidence required to take action and maintain focus on a plan.

In the class and in other discussions, the PhD students expressed concern about the direction of American education. They reported that the History of Science course, readings, and other discussions helped them to develop a more mature view of education and to ground their criticisms in fact and analysis. Their comments included the following.

- *The primary thing that stands out is that we teach science in this country as a layer cake. The idea that you are done with chemistry or physics in one year deprives students of the growth they need. The approach forces them to memorize without learning. … History shows how accidental the curriculum is.*
- *We met researchers from Cold Spring Harbor Lab. It's nice to develop those kinds of relationships; they are people I would not have met otherwise. … I think the program will give me a more universal view of science, and I may be able to take on greater responsibilities.*
- *I'm the only one not from a secondary school. I teach biology at Suffolk Community College. I have learned a lot from the program but if the program is going to attract people not in secondary education it might be good to focus more on science than on secondary education.*

<u>First Cohort: Fall 2011</u> (Based on interviews with Cohort 1 students, December 2011) Interviews conducted in the fall revealed that the Cohort 1 students had developed in a number of areas, since the evaluation visit and interviews eight months earlier.

Confidence in the Dissertation Process In the group discussion and interviews, most of the participants described their topics, the direction in which they were going, and said they were making progress. Several of the participants were developing plans, doing preliminary investigations, and collecting data from the institutions they hoped would be involved in their dissertations.

> *The program made me realize that I can do this. I think it has a lot to do with Angela (Dr. Kelly). She has given me a lot of confidence. She has shown us many PhD abstracts. It was not her intent to give us bad ones. But we realized that some were not too good.*

Increased Understanding of the Role of Research in Education One of those interviewed reported, based on readings and course discussions, that there is a significant gap between research and teaching—that the best of what has been learned in educational research is not being put into practice.

> *I have been learning so much from the articles. There are a lot of things we could be teaching. There is a disconnect between what people teach and the research; for example, kids learn best when they work together*.

Developing Skills to Assess Issues in Curriculum Development and Testing Dr. Sheppard's course on the history of science education as well as other components of the program provide the PhD students with a sense that understanding the current issues in science education can be useful in meeting today's needs. Several students said that the history course was more interesting and more relevant than they had expected.

Increased Understanding of the Nature of Science Although all of the participants had majored in science and had taught or were teaching science, they reported that through individual research projects and discussion they developed new understandings of science. Insights were related to ethical issues, the imprecise nature of science, and science as an ongoing process.

> *We spent time understanding what separates science from non-science; and there was a component in which we had to research a topic backwards, to the moment of its inception. Mine was about plate tectonics and the many theories about how mountains came about.*

Most were pleased with what they were learning and experiencing in a course requiring a literature review. Most believed that the literature would contribute directly to their dissertations. But a few found the search difficult because they did not have a very clear idea of their dissertation area.

<u>Second Cohort</u> Students in Cohort 2 were interviewed in small groups and a class was observed. The median age is younger than that of the first cohort and consequently the participants have less experience teaching. They reported that they were enthusiastic about the program. Their comments echoed those of the first cohort in learning about the history of science, methods and curriculum development, and the shifting priorities in science education. They also reported appreciating the program's individualized approach with the breadth and depth components and early introduction to dissertation interests.

The Ph.D. students gave a number of reasons for entering the program. Several aspired to work outside the classroom and talked about positions as science supervisors or curriculum coordinators. Several said they would like to teach in college after retiring from school systems. Others said simply that they had learned about the program when in the MAT program at Stony Brook.

- *I would like to become an expert in the field; nationwide there is a big push in science education, with the credential, I might be able to assist; requirements (of the program) will make me more competent as a department head.*
- *I would like to teach teachers, after retiring from teaching.*
- *I think it will definitely open up doors.*

Students in the second cohort discussed how the classes and discussions had raised a number of historical and social issues. They had gained an appreciation of how science education in the United States has come to its current situation; and they had some ideas about adjustments that might be made.

- *We learned something about the European system with its emphasis on apprenticeships. In this country we see college as the door to success. But it's not that way for everyone.*
- *Dr. Sheppard has encouraged us to focus on areas that we will pursue. … I have been thinking about it. It used to be that only one percent of the population went to school. Now it is reversed. We are forcing people to go to school. I'm interested in where the passion comes from, or the lack of it.*
- *It is challenging getting kids to see why science is important. A lot of teachers are not experts and not passionate about it. It's a job not a career.*
- *Our science department hasn't had money for science materials in 10 years; so we send these kids to college without the experiences they should have.*

In a class that was observed, one of the students provided a careful presentation of the International Baccalaureate curriculum with its various options, comparing and contrasting it with the advanced placement courses. This kind of exercise clearly sharpened the presenters analytical and assessment skills in ways that would be useful to a science curriculum planner, department head, or district coordinator.

<u>Dissertation Plans</u> Participants from both cohorts were pleased with the attention paid to the selection of a dissertation topic, literature review, and development of a research plan. Several of those in the first cohort had selected their topics, sites for data collection, and a reasonably clear statement of research questions and methods. Even those in the second cohort were hearing about how to approach the dissertation and were developing ideas.

<u>Manhattan</u> Cohort 3 of the PhD program in science education had three sections, one based in Manhattan and the other based at Stony Brook. The Manhattan cohort met at the Stony Brook Manhattan campus and follows exactly the same course of studies as the Stony Brook students. Part of the rationale for having a Manhattan cohort is to increase the diversity in the program and to include interactions with New York City Public schools (which is responsible for educating 38% of all students in the state).

All of the students in the Manhattan cohort worked in or with the public schools of New York City. These students provide a rich perspective on urban science education issues to the program. The cohort included classroom science teachers, district science coaches, and the education manager for the New York Academy of Science. The cohort had five females, two males. Students in the cohort made their first conference presentations in Fall 2014. The program intends to add additional Manhattan cohorts in the future.

<u>Summary of PhD Implementation</u> The PhD program in science education has been implemented successfully with a clear understanding of its mission and priorities. The director and staff have a breadth of experience and commitment to the improvement of American science education. The students have entered into the spirit of the program with energy, and each cohort has formed a cohesive group, with students supporting and encouraging one another. Together these elements form a solid foundation for continuing to build the program.

With its history and commitment to exploratory science education, CESAME has provided an ideal context and a wealth of resources for the program. Students in the program are receiving strong academic experiences in science and science education, and are learning in the context of a center for best practices in professional development.

The PhD program at Stony Brook is identifying and analyzing a number of the more important issues in science education. The program is equipping the next generation of specialists to introduce practices that will move science education in this country in the right direction, and in time the program is likely to create a model for doctoral studies in science education.

MAT Programs in Science and Mathematics Stony Brook, without a school of education, maintains strong masters programs in teaching. Some would argue that lacking a school of education is one of the reasons for the strong programs. Interviews with faculty as well as former MAT students have consistently pointed to two major strengths of the program: academic rigor and the quality of the clinical experiences. These two strengths are made possible and enhanced by a number of other interconnected features of the university and CESAME, described below.

Stony Brook University has a tradition of strong science departments. In recent years, CESAME has tapped into these resources to enhance the educational climate of the MAT program. Elements of the program include:

- Requirements that students take rigorous graduate courses;
- Research opportunities available for all students;
- Some courses that include scientific applications at levels appropriate for school teaching;
- Additional practical experiences through the CESAME network.

A student who had started an MAT program at another university made the following comments.

> *I enrolled in an MAT program at another university for a semester but it was terrible. The classes were not a rigorous. The students in my cohort seemed like they would not be good teachers. One woman said you just have to be a chapter ahead of the students. That blew my mind; that someone would be happy being a science teacher, without really knowing science. Teaching wasn't really that important. Even the methods classes were not that rigorous; you just show up and get a grade.*

When asked about the strengths of Stony Brook, the same student, who had been teaching at a Long Island high school for a few years, commented.

> *We had a lot of practice; you had to present in class multiple times, and it was not always teaching related. … One of the things I noticed comparing Stony Brook students with those from other places: Stony Brook graduates know their content at a deeper level; well, they don't have a school of education so everyone in the MAT program majored in science, not in teaching science. When you major in secondary education you are not as comfortable with the content. … The person who hired me said they had great experiences in the past with people from Stony Brook. So they were willing to stake the reputation of the school on graduates.*

One might think that the strong academic content of the Stony Brook MAT programs comes at the expense of the clinical portion. This however is not at all the case. Instructors in the methods courses bring an average of more than 20 years teaching to the program—much more than the faculty at some teacher training colleges. Their approaches to preparing lessons, curriculum development, classroom management, assessment, and guiding students are based on extensive experience and are grounded in the best of current pedagogy. An MAT graduate now teaching commented.

> *They (the supervising faculty) were very good showing how important it is to be hands-on; to use demonstrations, and to keep the kids involved. And they covered the little things like taking attendance, and doing little demos. No preparation can substitute for the actual experience of teaching, but I definitely felt ahead of the curve starting. I was very comfortable.*

In addition to the above, the MAT students at Stony Brook profit from the broad network and resources; some of which were made possible by HHMI, including:

- Participation in the teaching labs that bring hundreds of middle and high school students to the university. In these labs the MAT students interact with students, gaining insights into their thinking. In addition, they are able to work one-on-one with students.
- Observations and practice teaching at excellent sites on Long Island.
- Assisting with mathematics and science competitions sponsored by Stony Brook and CESAME, and with HHMI resources.

In summary, we can say that the MAT program is strong in its approach to theory and practice. And it boasts a five-year retention rate of more than 80%. Graduates have a strong sense of professionalism, with dedication to science and to teaching. They have become skilled and motivated in practicing and teaching exploratory science.

Professional Development for School Teachers Over the years CESAME has offered a number of summer workshops for teachers. One of the more successful series took place during the summers of 2010 and 2011 and was funded by the Toyota Foundation.

The program introduced teachers to a variety of hands-on, exploratory activities and addressed several issues in the New York State curriculum, the certification processes, and teacher interests. Earth science was considered particularly important for several reasons:

- More students take the New York earth science exam than take the chemistry and biology combined.
- There is a shortage teachers certified in earth science.
- Earth science has been under-valued in both high school and college programs, and there are efforts underway to redress this shortcoming.
- The geosciences department at Stony Brook has received an NSF grant providing activities for school students from the area and also for college students, with the goal of expanding interest in the geological sciences. The Toyota foundation grant works cooperatively with the NSF grant, sharing resources.
- Stony Brook University initiated a master's degree (MA) in earth science in the fall of 2011.

The evaluation included a visit to the campus with interviews and observations of classes and activities.

<u>Program Activities and Outcomes</u> The participants were both middle school and high school teachers. In brief conversations, during class activities and at lunch, they were highly positive

about the program and about teaching with more active, exploratory, and "real-world" activities.

Learning Particular Methods and Activities CESAME has developed hands-on methods for the professional development of schoolteachers in all of the science areas. The geosciences have followed the example of biology, physics, and other disciplines, developing a teaching lab. In this case the lab was prepared cooperatively using resources from several grants and from the department of Geosciences and CESAME.

Classes that were observed in the teaching lab demonstrated the variety of resources available, in terms of equipment, supplies, and experienced guides.

Developing a Research/Exploration Mentality One of the directors was asked whether the activities that the teachers were working with could be translated intact back to the schools. She said that the more important benefit was that the activities help inculcate a way of thinking, working with materials, collecting data, and problem solving. In other words the teachers were not so much gathering a collection of completed exercises as working on strategies and ways of thinking that they would then try to nourish in their students. While it is true that this larger goal is of great importance, it appeared that the teachers were also able to acquire methods that would be directly transferable to the classroom—with adjustments for the class level and other circumstances.

Botany The biology teachers were pleased that the program offered botany activities. They said that they and their students enjoyed botany even though it receives very little coverage in the curriculum. The visit to the Stony Brook greenhouse (Part of the Ecology and Evolution department) demonstrated that the methods of identification involved skills that could be transferred to other areas of science.

Preparing for New Challenges in the Classroom. Earth science has become something of a gatekeeper course in which many students decide whether or not they like science. Teachers view the course as an opportunity to engage students in hands-on, exploratory approaches. But because of the large numbers of students taking the class and their ages, classroom management problems often arise. In addition, inclusion strategies are increasing for working with special education students, and several of the teachers expressed concern that their classes in the coming school year would involve inclusion for the first time.

The program offered the teachers substantial binders of materials about the lessons, methods, and experiments covered. In addition, the procedures that were covered in classes will be available online. The teacher participants brought lessons and shared them one evening. In addition to these practices, there was a very healthy level of collegiality, with teachers informally sharing ideas and strategies.

Benefits to CESAME and Stony Brook The program provides another example of the high level of synergy existing among the programs and personnel at CESAME and across the Stony Brook campus, including:

- Geoscience program teachers and administrators who have experience in schools as well as in directing teacher workshops that feature exploratory learning;
- Faculty and administrators in the MAT and summer workshop programs who are also enrolled in doctoral programs in science education, and these programs together increase the participants understanding of issues and methods in pedagogy;
- Ongoing productive relationships with Long Island public school systems.

Survey Data The teacher participants were asked to complete surveys rating the different activities, field trips, and processes. Ratings on a five-point scale were consistently over 4, and in a few areas such as the permeability activity and stream table were at or close to 5. Comments were consistently positive about all aspects of the program. The only qualifications that teachers made were that some activities did not fit the curriculum they were following or that, because of their location, they would be less likely to use certain activities, such as those in marine science.

7 Critical Success Factors and the Future

In this final chapter we will consider the critical factors that account for CESAME's success. These factors are based on the data and analysis contained in the previous chapters. The factors we will describe are attributes of people and the organization, strategies employed, priorities, and circumstances. They might be considered "apples and oranges." But together they seem to account for the unusual, if not unique, evolution and success of CESAME.

Leadership and Funding David Bynum, founder of CESAME, frequently talks about entrepreneurship, and there is no better word to describe his own style. The entrepreneur is generally seen as one who has a fresh vision—about a product, business, or way of doing things. There are also social and educational entrepreneurs. To accompany and implement a vision, the entrepreneur needs skills in leadership, team-building, and management. In the development of CESAME, leadership was also closely tied to funding and staffing.

The educational vision of David Bynum and Keith Sheppard, his successor, has been to provide exploratory, exciting science experiences for students at all levels. In the earlier years, Bynum followed the leads of funding agencies: the Howard Hughes Medical Initiative, the National Science Foundation, National Institute of Health, and others. While this approach may seem to be reactive, it should be remembered that these foundations spend a great deal of time determining the needs of students, faculty members, institutions, and even the nation. Their requests for proposals are generally established with comprehensive science needs in mind; and their awards are made to individuals and institutions that are in a position to maximize the resources available to them.

Unlike most principal investigators for multi-million dollar grants, Bynum did not divide his time among teaching, research and the administration of grants. Although he may not have known exactly where the early grants would lead, his commitment to the budding organization was total. Also, unlike most grant administrators, he viewed the grants more as seed money than funding for programs that would flourish for a few years and then fade. As has been mentioned throughout this report, Bynum worked with the university when planning grants, insisting that if funded he would also receive faculty lines to augment the programs and insure sustainability. This approach of course strengthened the proposals and increased the likelihood of funding. Also, as was described above, Bynum made it a practice to secure fees from school districts or individuals when these were appropriate and affordable. This practice made it possible for the Center to reach a wider audience and to continue building a solid foundation.

Bynum and Sheppard are always on the lookout for new opportunities, projects, courses to sponsor, and people. In staffing, they are essentially team-builders—in so far as possible, finding and hiring competent people and then giving them a range of opportunities within the activities of grants or newly designed projects. They do not micro-manage, but carefully review each new venture, course, or workshop—and if not satisfied, they make changes. The vision is clear—science in action in today's world, with research at all levels. In general those working in the organization understand and value the opportunity to work in the setting that CESAME provides.

Staffing With Multiple Responsibilities* and *Co-Appointments All of those who teach within CESAME have responsibilities with several projects or programs. The director of the Biology Teaching Lab co-teaches a research course, devotes most summers to intensive workshops for advanced high school students, and coordinates the annual Protein Modeling Competition. Others who teach special grant-funded courses have assignments within the university as researchers, lecturers, adjuncts, or regular faculty members. Several retired teachers who supervise student teachers in the MAT program, are themselves candidates for the Ph.D. in science education. Every year, several of those in the MAT program, assist in the teaching labs for high school students. Recent hires have included several important areas for each individual: co-teaching within the university's science departments, combined with discipline-based research in education, and the expertise required to teach and advise in the PhD in science education program.

CESAME-connected faculty when asked about the strengths of the Center and its programs, all pointed to leadership and teamwork. They know that they are trusted and they work together in so many capacities that they are thoroughly invested in the enterprise. In addition, the following benefits are apparent:

- With a dozen or more people sharing their time and responsibilities across CESAME and across the university, the Center maintains close ties with science departments as well as with administrators and key decision makers in the university.
- Research in pedagogy is closely tied to practice.
- Teaching and learning are undertaken in the spirit of research with hypothesis testing, review of variables and outcomes, and program revision based on outcomes.
- CESAME is demonstrating new methods of teaching and research to faculty members in the university's science departments.

Innovation David Bynum has said that innovation is at the core of our success as a nation but it is the last thing you find in education. He believes that schools and colleges, as they are generally run, tend to stifle creativity and excitement. "It drives people away; who wants to go into a field that stresses compliance so much?"

A determination to make learning exciting has led Bynum and Sheppard to innovate and to adopt many of the activities and programs described in this report. The teaching labs, school-level competitions, research for high school students and undergraduates, in-service for teachers, as well as the MAT and doctoral programs all strive to do things differently—not because being different is important in itself, but because American education needs change.

CESAME's success within and beyond the university, as well as the long history of exploratory and project-based teaching and learning testify to the benefits and success of the priorities and activities we have explored in this report. And most of these activities are based on efforts to develop new solutions to contemporary problems in teaching and learning. School teachers and university faculty members are hungry for new ways to go about teaching and to inspire learning; CESAME is showing them how to do it.

Collaboration Within and Beyond the University It is interesting and somewhat remarkable that CESAME's spirit of innovation has flourished within the context of collaboration. Earlier in this chapter we discussed how individual faculty members in CESAME work with several groups, departments, and projects. In this regard their professional lives are more partnership-oriented than is common for the average teacher or professor.

This spirit and exercise of collaboration extends beyond the individual and is a characteristic of the organization. CESAME partners with:

- Departments of the university, particularly the biology departments, in developing new teaching methods, approaches to curriculum, and educational research activities.
- Laboratories on Long Island, supporting post-doctoral researchers, and collaborating on grants.
- School districts, with special activities, competitions, and summer programs.
- Funding organizations, following priorities and consulting in the execution of grant-related projects.
- Administrators and offices at the university, supporting and promoting new innovative educational practices in areas such as journalism, communicating science and training teaching assistants.

The fact that CESAME achieves this combination with relative ease indicates that many of those engaged in education are in fact looking for fresh approaches to teaching and learning within a collaborative framework.

No School of Education American educators are now familiar with the recent history of education in Finland and which was described earlier in this report. Finland closed its schools of education, moved teacher training to the major universities, raised requirements for teacher training—and the rest is history.

American programs in teacher preparation have been faulted in recent years for mediocrity in virtually all areas—rigor of courses offered, academic level of applicants, and overall requirements for completion. Few programs have been cited as high quality. We cite from one study. “Through an exhaustive and unprecedented examination of how these schools operate, the Review finds they have become an industry of mediocrity, churning out first-year teachers with classroom management skills and content knowledge inadequate to thrive in classrooms with ever-increasing ethnic and socioeconomic student diversity” (NCTQ, 2013).

Not all schools of education suffer from the problems mentioned above. But all bring a level of bureaucracy—within and beyond the university. For these and other reasons, CESAME’s leaders believe strongly that the lack of a school of education has positive value contributing to the success of the Center. A newly opened school of education would have to prove itself both within and beyond the university, and would probably be led to set up an undergraduate program in teacher education. As it is, CESAME must comply with requirements for awarding degrees and certificates. But the Center retains a very broad and healthy level of independence in the way it works with students, sets priorities, does research, and plans for the future.

Research in Education CESAME’s work proceeded over the years with a strong emphasis on doing science, and this included an introduction to research for high school and community college students, as well as sponsored research for undergraduates, and support for the annual URECA research day, described above. Research and exploratory science are therefore at the heart of CESAME’s mission.

Research in education however was not an early priority. But the implementation of the doctoral program in science education and the hiring of faculty with experience and expertise in educational research, as well as current national priorities—all of these factors have led the leadership of CESAME to place a high priority on research in education.

Dr. Sheppard’s research activities include studying the historical development of the science curricula, investigating teachers’ conceptual understanding of science and the learning of science in informal educational settings. He is widely published in the field of science education and recent articles can be found in the *Journal of Chemical Education*, *The Physics Teacher* and *CBE-Life Sciences Education*.

Dr. Kelly's research interests include inequities in secondary physics and chemistry access, science teacher recruitment and retention, pedagogical content knowledge in the physical sciences, and educational technology in the science classroom. She has given numerous presentations at national and international conferences, and has published recent work in *The Physics Teacher, Journal of Curriculum and Instruction, Science Educator, American Journal of Physics,* and *The New Educator Journal.*

Dr. Nehm's research interests include scientific thinking and problem solving, knowledge measurement and assessment, science misconceptions and conceptual change, multicultural science education, science textbooks and knowledge representation, and evolution education. Dr. Nehm has authored or co-authored 50 journal articles and book chapters and presented more than 100 conference talks and papers. He has published in a wide array of education and science journals, including the *Journal of Research in Science Teaching, Science Education, Science & Education, International Journal of Science Education, Research in Science Education, Journal of Science Teacher Education, The American Biology Teacher, Journal of Science Education and Technology, CBE-Life Sciences Education, Evolution Education and Outreach, Genetics, Journal of Paleontology*, and several others.

The Future As has been noted throughout this report, the Center for Science and Mathematics Education, began small and grew in an organic and evolutionary manner. The Center took advantage of opportunities in the educational environment. Its foundation was built not so much or organizational structures as on successful practice and dedicated individuals. The growth of the Center and its attachment to Stony Brook University has however led to a solid organization with secure funding and plans for the future.

One of the more important of CESAME's priorities is to further impact undergraduate learning in the STEM disciplines. To this end and to institutionalize its outreach efforts, the Center applied for and has been designated as an Institute within the university. Achieving this status and recognition provides the status, funding, and commitment from the University that are required for ongoing success. The application for the Institute stated the following.

> The SBU STEM Education Institute will integrate all levels of STEM education and link currently isolated entities to increase research funding, improve learning outcomes, and enhance student retention. SBU will continue to develop as a nationally renowned center of excellence in STEM education with commitment to improving the quality of STEM teaching and learning through innovative research, excellent teaching, strategic partnerships and external support.

The document describes the following goals.

> The goals of the STEM Education Institute are aligned with the mission of the University and fall within four core areas: 1) improving undergraduate STEM education, 2) broadening the impacts of our Ph.D. Program in Science Education, 3) strengthening science teacher education, and 4) building capacity for academic outreach. The rapid growth and success of the Center for Science & Mathematics Education (CESAME) necessitates an expanded infrastructure to maintain and increase its effectiveness. The

formal designation of the STEM Education Institute will facilitate the University's systemic commitment to meeting these goals.

The designation of Institute promises to validate the Center's successes and provide a guarantee that the innovative, entrepreneurial and research-based approach to education will further advance within Stony Brook University, and beyond.

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References and Bibliography

Alexander, B. B., Foertsch, J. A., Daffinrud, S., & Tapia, R. (2000). The spend a summer with a scientist (SaS) program at Rice University: A study of program outcomes and essential elements, 1991-1997. *Council for Undergraduate Research Quarterly, 3*, 127-133.

Astin, A. W. (1984). Student involvement: A developmental theory for higher education. *Journal of College Student Personnel*, *25*, 297-308.

Blackboard Institute, Closing the gap between high school and college (2013). pdf Retrieved from https://www.google.com/search?source=ig&rlz=&q=Closing+the+gap+between+high+school+and+college

Bonsangue, M., & Drew, D. E. (1992). *Long-term effectiveness of the calculus workshop model.* Report to the National Science Foundation. Washington: NSF.

Dewey, J. (1962). *Schools of tomorrow.* New York: E. P. Dutton. (Original work published 1915)

Drucker, P. F. (1986, HarperBusiness, 1993). *Innovation and entrepreneurship.* New York: HarperColllins.

Gafney, L. (2001). The impact of research on undergraduates' understanding of science*, The Council on Undergraduate Research Quarterly, 21,* 172-176.

Gafney, L. (2005). Student and faculty views of the research mentor/teacher. *Journal of College Science Teaching*, *34(6),* 52-56.

Gafney, L., & Varma-Nelson, P. (2008). *Peer-led team learning: Evaluation, dissemination, and institutionalization of a college level initiative.* Dordrecht: Springer.

Gardner, J. W. (1961). *Excellence: Can we be equal and excellent too?* New York: Harper & Row.

Hanson, D. (2006). *Instructor's guide to process-oriented guided inquiry.* Lisle, IL: Pacific Crest.

Halpern, D, F. (1994). Rethinking college instruction for a changing world. In Halpern, D. F.& Associates (Eds.), *Changing college classrooms* (pp. 1-12). San Francisco: Jossey-Bass.

Kao, J. (2007). *Innovation nation: How America is losing its innovation edge, why it matters, and what we can do to get it back*. New York: Free Press.

Kiely, J., Kelly, A.M., La Magna, K., Moloney, D., & Bynum, R.D. (2014, January). *Biotechnology teaching laboratories: University outreach for science teacher professional development and* *advanced STEM learning.* Presentation at the Annual Conference of the Association of Science Teacher Education, San Antonio, Texas.

Kimbrough, W. M. & Harper, S. R. (2006). African American men at historically black college and universities: Different Environments, similar challenges. In Cuyjet, M. J. (Ed.), *African American men in college* (pp 189-209). San Francisco: Jossey-Bass.

Kuh, G.D. (2003). What we're learning about student engagement from NSSE. *Change*, *(2),* 2433.

Light, R. J. (2001). *Making the most of college: Students speak their minds*. Cambridge: Harvard University Press.

Lopatto, D. What undergraduate research can tell us on research on learning. *Project Kaleidoscope Volume IV.* Retrieved from http://www.pkal.org/documents/Vol4WhatUndergradResearchCanTellUs.cfm

Loveless, T. (2012). *How well are American students learning?* Brown center report. Vol. 3, No. 1.

Lovitts., B. E. (2001). *Leaving the ivory tower: The causes and consequences of departure from doctoral study.* Lanham, MD: Rowman & Litlefield.

NCTQ, National Council of Teacher Quality (2013). Retrieved from http://www.nctq.org/dmsView/Teacher_Prep_Review_executive_summary

Mazur, E., (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall.

Miller, J. E., Groccia, J.E., & Miller, M.S. (Eds.) (2001). *Student-assisted teaching: A guide to faculty student teamwork*. Bolton, MA: Anker Publishing Company.

UMBC An Honors University in Maryland, *Meyerhoff Scholars Program: 13 Key Components*. Retrieved Sept. 9, 2014 from http://meyerhoff.umbc.edu/13-key-components/

Miller, L. S. (1995). *An American imperative: Accelerating minority educational advancement.* New Haven: Yale University Press.

PISA, https://nces.ed.gov/surveys/pisa/

RAND website (2013) www.rand.org/topics/education-and-the-arts.html

Ripley, A. (2013) *The Smartest Kids in the world and how they got that way.* New York: Simon and Schuster.

Scheirer, M. A. (2005). Is sustainability possible? A review and commentary on empirical studies of program sustainability. *American Journal of Evaluation, 26*, 320-347.

Seymour, E., Hunter, A.B., Laursen, S.L., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates: First findings from a three-year study. *Science Education*, *88*, 493-534.

Sheppard, K. The history and future of science education reform. *Invited Talk at the New York Academy of Sciences.* New York, NY. (October 13th, 2006). Available through http://www.nyas.org/Publications/Ebriefings

Sheppard, K. & Gunning, A. (In Press) The roots of physics teaching: The history of physics teacher education in the USA. Book Chapter in *Effective Practices in Pre-service Physics Teacher Education.* The American Physical Society.

Stigler, J. W. & Hiebert, J. (1999). *The teaching gap.* New York: Free Press.

The educational pipeline: Big investment, big returns (2013, September). Retrieved from http://www.highereducation.org/reports/pipeline

Tinto, V. (1997). "Classrooms as Communities: Exploring The Educational Character of Student Persistence" *Journal of Higher Education. 68*, 6, 599-623.

Thorpe, T. & Goldstein, B 9 (2010). *Engines of innovation: The entrepreneurial university in the twenty-first century.* Chapel Hill: UNC Press.

Tobias, S. and Raphael, J. (1997). *The hidden curriculum: Faculty-made tests in science.* New York, NY: Plenum.

Treisman, P. M. (1992) Studying students studying calculus: A look at the lives of minority mathematics students in college. *The College Mathematics Journal*, *23* (5), 362-372.

U. S. Department of Education. (2010) *A blueprint for reform: The reauthorization of the elementary and secondary education act*.

Venezio, A., Kirst, M. W., & Antonio A. L. (2012, March) *Betraying the college dream: How disconnected K-12 and postsecondary education systems undermine student aspirations (Final policy report from Stanford university's bridge project).* Retrieved from http://www.google.com/search?source=ig&rlz=&q=Betraying+the+Dream

Walker, G. E., Golde, C. M., Jones, L., Bueschel, A. C., Hutchings, P. (2008). *The formation of Scholars: Rethinking doctoral education for the twenty-first century.* San Francisco, CA: Jossey-Bass.

Wilson, K. G. & Davis, B. (1994). *Redesigning education.* New York: Teachers College Press.

The Woodrow Wilson National Fellowship Foundation. (2005). *Identifying and developing the best minds.* Retrieved from http://www.woodrow.org/news/news_items/Diversity_PHD_0505.php