The U.S. STEM Undergraduate Model

Applying System Dynamics to Help Meet President Obama's Goals for One Million STEM Graduates and the U.S. Navy's Civilian STEM Workforce Needs

BHEF BUSINESS-HIGHER EDUCATION FORUM®

Creating Solutions. Inspiring Action.

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BHEF is the nation's oldest membership organization of Fortune 500 CEOs and research university presidents dedicated to advancing innovative education and workforce solutions and improving U.S. competitiveness. Now in its 35th year, BHEF's business and academic members collaborate in regions across the country to design and deploy education-workforce solutions in fields that are critical to innovation and national security. BHEF and its members drive change locally, work to influence public policy at the national and state levels, and inspire other leaders to act.

BHEF would like to recognize the individuals, federal agencies, and organizations instrumental in the research, design, and development of the U.S. STEM Undergraduate Model. The model will stand as an invaluable resource to policy and decision makers. Additionally, it is a significant step forward in the utilization of system dynamics modeling for our nation's STEM education pipeline. Your enduring commitment to the insights gleaned and the future success of students engaged in STEM education was evident throughout this effort, and we value your partnerships tremendously.

We thank the U.S. Navy, the Office of Naval Research, the U.S. Department of Defense, Carderock Naval Surface Warfare Center, the U.S. Naval Academy, the National Science Foundation, workshop participants, intervention specialists, and model reviewers. BHEF is especially grateful to Linda Nguyen and Dan Sturtevant from Emtect Solutions, as well as Kimberly Holmes and Steve Pelletier.

Your collective efforts have created an important contribution to America's education infrastructure and future workforce, and we thank you.

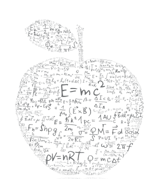
Infographics: Elefint Designs, pages 7-8 and 11-12.

All references for this report are included in the Literature Review Summaries document available at *www.bhef.com*.

The Business-Higher Education Forum
2025 M Street NW, Suite 800
Washington, D.C. 20036

For more information about BHEF, visit *www.bhef.com*.

The U.S. STEM Undergraduate Model



Foreword

The United States Navy maintains its technological edge through a dynamic portfolio of scientific research and technology development, a culture of innovation, and the capacity to draw upon diverse ideas and approaches. To sustain that edge, the Navy must able to recruit and retain a civilian workforce that is strongly skilled in science, technology, engineering, and mathematics (STEM).

Like many other government agencies as well as organizations in the private sector, however, the Navy faces the challenge of finding staff with sufficiently strong skills in the STEM disciplines. Recognizing the severity of this issue at the national level, President Obama has called for colleges and universities to produce one million more graduates in STEM fields.

To meet its own needs for robust STEM talent, and to contribute toward the president's goals, the Navy has taken a proactive leadership role. Under the Naval STEM Strategy and through such initiatives as the Office of Naval Research's STEM2Stern initiative, the Navy pursues a comprehensive strategy designed to create a "one Navy" approach to STEM and to better leverage Navy resources in developing STEM capacity. Among other priorities for that work, the Navy seeks to inspire the next generation of scientists and engineers and to engage students and build their STEM confidence and skills through hands-on learning activities that incorporate Navy-relevant content.

In its unique and distinctive work, the Business-Higher Education Forum has applied system dynamics modeling as a means to better understand the U.S. STEM challenge. BHEF found, for example, that STEM undergraduate education represents the highest leverage strategy for increasing the number of STEM graduates. Given the Navy's interest in maximizing the impact of its investments in undergraduate STEM education, the Office of Naval Research (ONR) awarded BHEF a grant to develop a next-generation **U.S. STEM Undergraduate Model** that applies system dynamics modeling to show how ONR's investments in high-impact, cutting-edge STEM student retention strategies can have the strongest impact on the Navy's future workforce needs.

This report shows how insights gained from system dynamics modeling can help inform the Navy's strategy to grow a robust civilian workforce that is strongly invested with Navy-relevant STEM skills and ready to contribute to the next generation of Naval innovation. This work positions the Navy to serve a strong national leadership role in advancing President Obama's goals in STEM precisely while it enhances Naval STEM capacity. That powerful synergy is doing much to advance important improvements in the shaping and execution of the STEM education pathway.

Executive Summary

To sustain its historic strength in science and technology, the United States needs a workforce of professionals with robust skills in science, technology, engineering, and mathematics (STEM). In the United States, however, STEM degree production has not kept pace with STEM workforce needs, projected to grow by 17 percent over the next decade.

In February 2012, the Executive Office of the President, led by the Office of Science and Technology Policy (OSTP) and the President's Council of Advisors on Science and Technology (PCAST), released a report to the President entitled *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*. The report outlined common goals and framed a federal strategy for improving STEM education during the first two years of college, the period when students, particularly women and underrepresented minorities, are most likely to drop out of STEM fields. When the report was released, President Obama called for the nation to produce one million additional STEM graduates by 2020.

Applying System Dynamics to Help Meet the President's Challenge

The president's goal presents a significant opportunity to better understand what kinds of interventions are most effective in increasing student persistence toward STEM degrees; how, why, and in what combination do they work; and, most importantly, what successful retention strategies look like at scale. BHEF has taken a significant step forward in understanding the STEM challenge through its pioneering application of system dynamics in developing the U.S. STEM Undergraduate Model. Focused on post-secondary interventions that reduce attrition for each targeted year, the model simulates the stocks and flows of students as they move through the K-12 system, into post-secondary education, and into their STEM career choice.

Calibrated on the president's goal of reaching one million new STEM graduates by 2020, the model contextualizes this goal by providing a nuanced understanding of what actions and policies need to be in place to meet the STEM graduate challenge. The model also aligns closely with BHEF's goal to identify new forms of collaboration among business and industry, higher education, and government to increase the persistence of students, particularly women and underrepresented minorities, who graduate in STEM fields.

Key insights from the U.S. STEM Undergraduate Model show that:

- Reaching the PCAST goal of one million new STEM graduates will require a **large-scale disruption** of undergraduate education practices.
- **New models of engagement** with industry and universities in which students receive multiple interventions, some relatively low-cost, in freshman and sophomore years can maximize persistence and yield higher return on investment.
- Investments in interventions in the **early undergraduate years** can be targeted to the most at-risk students and the highest-demand fields—including emerging trans-disciplinary specialties such as cybersecurity and data analytics—to maximum effect.
- **Disruptive strategies**, including course redesign and intelligent course tools, and **new programs**, such as cybersecurity, offer powerful scaling opportunities.

Applying the U.S. STEM Undergraduate Model to Help Meet the U.S. Navy's STEM Challenge

The United States Navy Office of Naval Research (ONR) asked BHEF to apply the model to show how its investments in cutting-edge STEM student retention strategies can have the strongest impact on the Navy's future workforce needs. Insights from the model inform the Navy's strategy to grow a robust civilian workforce that is strongly invested with Navy-relevant STEM knowledge and skills, and ready to contribute to the next generation of Naval innovation.

This work positions the Navy to not only strengthen its civilian STEM workforce, but to serve in a strong national leadership role in advancing President Obama's goals. That powerful synergy has the potential to advance important improvements in the shaping and execution of the STEM education pathway.

Of course, ONR cannot be expected to meet the president's goal on its own. Addressing that challenge will require broad collaborations that engage federal agencies, business and industry, and higher education in partnerships to develop and test comprehensive programs that significantly increase retention and graduation of students in STEM disciplines. Working together, these key stakeholders can provide the critical leverage needed to scale solutions for meeting the president's goals—solutions that ultimately will strengthen America's capacity and competitiveness in STEM.

Letter from the Chair

Dear Colleagues,

A STEM-ready workforce will ensure both the success of future generations and our nation's economic strength. Building that workforce requires a strong partnership among business, higher education, and government. To that end, the Business-Higher Education Forum (BHEF) is proud to be working with the Office of Naval Research to help meet the Navy's STEM needs and to advance the president's goals for STEM education.

Celebrating its 35th year, BHEF is the nation's oldest organization of senior business and higher education executives dedicated to advancing innovative solutions to U.S. education and workforce challenges. BHEF members are national thought leaders, who convene like-minded colleagues from business, government, NGOs, and higher education to develop shared national policy agendas and actively implement them through regional efforts.

In February 2012, BHEF expressed enthusiastic support for *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*, a report to President Obama from the President's Council of Advisors on Science and Technology (PCAST).

The PCAST report outlined a federal strategy for improving STEM education during the first two years of college. Its recommendations align closely with BHEF's goal to identify new forms of collaboration among business and industry, higher education, and government to increase the persistence of students, particularly women and underrepresented minorities, to pursue degrees in STEM fields; deepen STEM knowledge and skills; and strengthen the alignment of undergraduate STEM education with workforce needs. These goals are at the core of BHEF's Higher Education and Workforce Initiative, a model of strategic business engagement in higher education to address America's workforce needs.

With the support of the U.S. Department of the Navy Office of Naval Research, BHEF has developed a powerful system dynamics tool, the BHEF U.S. STEM Undergraduate Model®, to inform strategies that can assist the Navy in developing a civilian workforce with strong STEM skills—and contribute to meeting the president's goals as outlined in the PCAST report. This work dovetails with BHEF's commitment to leverage its unique membership of executives from business and academe, the power of the model, and our expertise to employ evidence-based strategies to help meet the president's PCAST goals.

This commitment fuels BHEF's National STEM Undergraduate Partnership and the BHEF member-led regional projects. Supported by research, these efforts promote strategic collaboration between business and higher education and drives innovation. I encourage you to turn the insights and the U.S. STEM Undergraduate Model into action. Identify your region's unique workforce needs, and join BHEF's efforts as our members bring groundbreaking solutions to our nation's workforce challenges. Together, we can meet the president's goals.

Sincerely,

Wes Bush
Chairman, CEO and President, Northrop Grumman Corporation
BHEF Chair

Letter from the CEO

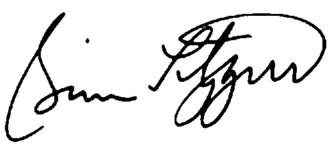
Dear Colleagues,

From the first engagement with the U.S. Office of Naval Research, we recognized that the system dynamics modeling that produced the BHEF U.S. STEM Education Model® could be applied to help identify the most promising strategies for developing a stronger STEM capacity in the U.S. Navy's civilian workforce. It is an ongoing privilege for BHEF to contribute to the Navy's mission and the nation's security in this way.

I was honored to have served on the working group charged with developing the President's Council of Advisors on Science and Technology's (PCAST) report on STEM undergraduate education. Insights from developing the initial version of the model helped to shape the report, *Engage to Excel*, which identified actions that President Obama could take through federal agencies to graduate one million additional students in STEM fields. Through its work to apply system dynamics modeling as a means to better understand the U.S. STEM challenge, BHEF had determined that STEM undergraduate education represents the highest leverage strategy for increasing the number of STEM graduates.

BHEF's work with the Navy has enabled us to refine the model and to derive even richer insights—findings that ultimately will both bolster the Navy's strength in STEM and enable it to contribute significantly to meeting the goals framed in the PCAST report. In short, we believe this work positions the Navy to serve a strong national leadership role in advancing President Obama's goals in STEM precisely while it enhances Naval STEM capacity. That powerful synergy is doing much to advance important improvements in the shaping and execution of the STEM education pathway.

Sincerely,



Brian K. Fitzgerald, Ed.D.
CEO
BHEF

About STEM2Stern

STEM programs rely heavily on Naval scientists and engineers serving as volunteers and mentors. These individuals come from a variety of backgrounds, but they all share a commitment to inspiring young people, their schools, and communities.

To address the increasing demand for top STEM talent and to identify more effective mechanisms for cross-Navy STEM program coordination, the Navy created a STEM investment strategy known as STEM2Stern. Under the leadership of the Chief of Naval Research, STEM2Stern promotes effective coordination and collaboration across the Naval STEM portfolio. The STEM2Stern coordination office works with the Naval laboratories, warfare centers, and other research and education institutions to ensure that the impact of the Navy's entire STEM education portfolio is maximized.

The STEM2Stern effort identifies gaps in the current portfolio as well as opportunities for future investment and support and for potential policies and procedures that could bolster the Navy's STEM-related work. Students, parents, teachers, and mentors can seek new programs and partnerships to strengthen local STEM educational programs on the STEM Web portal at *www.STEM2stern.org*. By offering a broad range of STEM education and outreach programs, the Navy seeks to address the national challenge of decreasing college enrollments and careers in science and engineering.

As part of this effort, the Navy and Marine Corps support American students throughout their education. In their K-12 programs, hands-on learning experiences—such as robotics competitions and internships—are emphasized to encourage students and teachers of all ages to "learn by doing." In their college and university programs, the focus is on research opportunities as well as summer internship work experiences and scholarships. STEM programs rely heavily on Naval scientists and engineers serving as volunteers and mentors. These individuals come from a variety of backgrounds, but they all share a commitment to inspiring young people, their schools, and communities.

The President's Council of Advisors on Science and Technology (PCAST)

The President's Council of Advisors on Science and Technology (PCAST) is an advisory group of some of the nation's leading scientists and engineers who directly advise the president and the executive branch. PCAST makes policy recommendations in the many areas in which an understanding of science, technology, and innovation is key to strengthening our economy and forming policy that works for the American people.

The PCAST Challenge

On February 7, 2012, the White House announced the release of a major report from the President's Council of Advisors on Science and Technology, *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*. That same day, President Obama announced his support for one of the report's central goals—that the United States produce one million additional college graduates in STEM fields over the next decade.

The PCAST report found that students in the United States currently earn approximately 300,000 bachelor and associate degrees in science, technology, engineering, and math fields annually. It also found that fewer than 40 percent of students who enter college intending to major in a STEM field follow through and complete a STEM degree. The report indicated that "[m]any of those who abandon STEM majors perform well in their introductory courses and would make valuable additions to the STEM workforce."

"Increasing the retention of STEM majors from 40 percent to 50 percent would, alone, generate three quarters of the targeted one million additional STEM degrees over the next decade," the report stated. Moreover, "retaining more students in STEM majors is the lowest cost, fastest policy option to providing the STEM professionals that the nation needs for economic and societal well-being."

Among its many insights and contributions, the PCAST report underscored that the first two years of undergraduate education are critical leverage points for building and retaining student interest in STEM. Reflecting that finding, the report focused on actions that would influence the quality of STEM education in the first two years of college. Based on extensive

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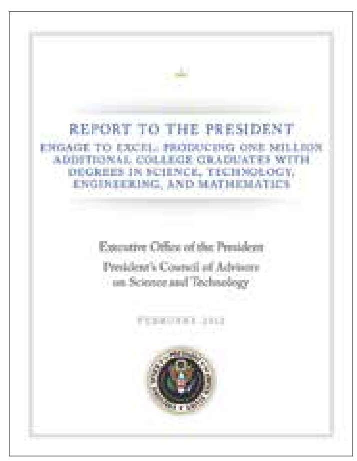
Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics



research about students' choices, learning processes, and preparation, the report outlined three steps to improvement that should be considered "imperatives":

- Improve the first two years of STEM education in college;
- Provide all students with the tools to excel; and
- Diversify pathways to STEM degrees.

Among other strategies for converting its "imperatives" to action, the report encouraged the creation of partnerships among many stakeholders to diversify pathways to STEM careers. Indeed, the report specified that its very title, *Engage to Excel*, "applies to students, faculty, and leaders in academia, industry, and government." Calling for the creation of public-private partnerships to support successful STEM programs, for example, the report said that "[t]o enhance students' STEM readiness, the Federal Government should engage private industry and foundations to support successful programs."

Truly a landmark report, the PCAST document is seminal for several reasons. It built consensus around the research-based understanding that the first two years of undergraduate education are critical leverage points for students to persevere toward STEM degrees and ultimately join the STEM workforce. The report created a central resource for identifying high-impact exemplar programs (such as the Meyerhoff Scholars at the University of Maryland, Baltimore County and Biology Undergraduate Scholars Program at the University of California-Davis). Finally, the PCAST report also served as a definitive source of highly vetted, leading studies on undergraduate STEM education that focus on and highlight the importance of undergraduate research, active student learning and course redesign, and the ongoing need to target support specifically toward women and underrepresented minorities.

The PCAST report left open the question of how federal agencies and partners could best approach its important call to action. This report describes important work by the U.S. Navy and the Office of Naval Research to meet that challenge. As part of its comprehensive STEM strategy, ONR engaged the Business-Higher Education Forum to adapt BHEF's unique system dynamics STEM model to simulate and assess evidence-based STEM education strategies that can be scaled to better address the U.S. Navy's workforce needs—and simultaneously show pathways for the Navy to contribute toward the PCAST goal of adding one million more STEM graduates over the next decade.

The Navy's Challenge

The Navy maintains its technological edge through a dynamic portfolio of scientific research and technology development, a culture of innovation, and the capacity to draw upon diverse ideas and approaches. It is imperative, therefore, that the Navy be able to recruit and retain a workforce that is highly skilled in science, technology, engineering, and mathematics. Like many other government agencies as well as organizations in the private sector, however, the Navy faces the challenge of finding staff with sufficiently strong skills in the STEM disciplines. Moreover, due to impending retirements and attrition, the Navy anticipates 5,000 openings in its civilian STEM workforce between now and 2020.

The Navy has taken a proactive leadership role in working to meet this challenge. In 2009, ONR launched its STEM2Stern initiative, a comprehensive strategy designed to create a "one Navy" approach to STEM and to better leverage Navy resources and maximize the impact of its STEM investments. Subsequently, in 2011, the Navy released the Naval STEM Strategy, which identified these specific goals:

- Double investment in STEM by 2015;
- Focus on high-engagement, long-duration programs;
- Focus on expanding participation of underrepresented populations;
- Integrate naval relevance/needs into programs; and
- Develop simple, practical, and meaningful metrics.

The Navy's STEM Roadmap is built around five priorities that combine best-in-class experiences for students alongside the needs of the Navy for a STEM workforce pipeline. Initiatives include exciting new programs that will increase participation by students and teachers, allow for hands-on and meaningful learning experiences, and meet the underserved where they live. The five priorities are:

- *Inspire* the next generation of scientists and engineers;
- *Engage* students and build their STEM confidence and skills through hands-on learning activities that incorporate Naval-relevant content;
- *Educate* students to be well prepared for employment in STEM careers that support the Navy and Marine Corps;
- *Employ*, retain, and develop Naval STEM professionals; and
- *Collaborate* on STEM efforts across the Department of the Navy, the federal government, and best practice organizations.

ONR has identified improving STEM-related outcomes in higher education through evidence-based interventions as a key priority—particularly focusing on the first two years of college, where research has shown the most impact can be gained.

Using System Dynamics to Better Understand the Navy's STEM Investment Opportunities

To help meet its most critical challenges, the Navy must recruit and retain a civilian workforce that is highly skilled in science, technology, engineering, and mathematics to contribute to the next generation of Naval innovation. This need is even more acute as current employees retire, and it is compounded by the reality that our nation's universities are not producing graduates in STEM fields in numbers adequate to meet workforce demand.

To meet this need, and to better understand how the Navy can maximize its investments in undergraduate education, ONR asked BHEF to apply system dynamics modeling as a means to show how ONR's investments in high-impact, cutting-edge STEM student retention strategies could have the strongest impact on the Navy's future workforce needs. Insights gained from system dynamics modeling help inform the Navy's strategy to grow a robust civilian workforce that is strongly invested with Navy-relevant STEM skills and ready to contribute to the next generation of Naval innovation.

By definition, the process and products related to the development of a system dynamics model provide a comprehensive and organized approach to help understand the behavior of a system over time and at scale. This approach allows a complex system, such as the U.S. STEM education pipeline, to be deconstructed into specific components that can be examined simultaneously. The approach can also be used to examine the effectiveness of proposed solutions in order to assist decision-makers in setting priorities and guiding policy making.

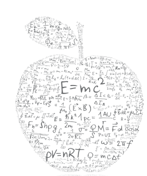
BHEF's original U.S. STEM Education Model® is a system dynamics model that was developed by systems engineers at the Raytheon Company in collaboration with BHEF staff and donated to BHEF in 2009. It simulates the impact of various policies and programs on the number of graduates in the STEM disciplines who go on to pursue STEM industry careers. This first-of-its-kind model showcased to policymakers, educators, and researchers the complex structure of the U.S. STEM education system and enabled users to test different intervention scenarios that could help strengthen student outcomes in STEM. This initial model provided the first step in understanding the impact of individual discrete interventions, such as increasing a teacher's salary or placing all students into cohort living/learning programs, on the production of STEM capable graduates.

"BHEF's efforts to develop enhancements to the U.S. STEM Education Model will help our nation secure the strong STEM talent pipeline which is critically important for us to continue as an innovation leader."

William H. Swanson, Chairman and CEO,
Raytheon Company

The key insights from this model were two-fold, indicating that 1) the highest leverage point for investment in STEM education is at the undergraduate level, and 2) evidence-based intervention strategies applied at the undergraduate level can have a significant effect on the graduation rates and trajectory of the STEM workforce.

In 2012, the Navy awarded a grant to BHEF focused on developing a next-generation version of the model, the U.S. STEM Undergraduate Model, which focuses on the undergraduate portion of the pipeline and directly ties the model to undergraduate STEM retention and graduation in alignment with the ONR STEM2Stern priorities and the PCAST goal of one million additional STEM graduates.



CLOSING THE NAVY'S STEM WORKFORCE GAP

Maintaining a technological edge require
and technology development, a culture of
diverse ideas and approaches. A strong
success of the U.S. Navy. However, the
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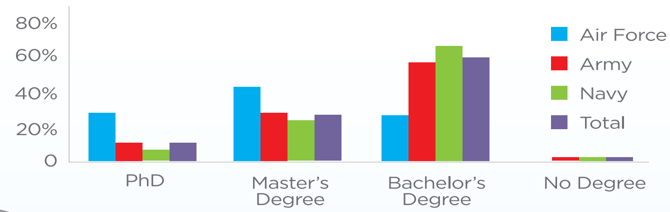
between now and 2020, and filling these

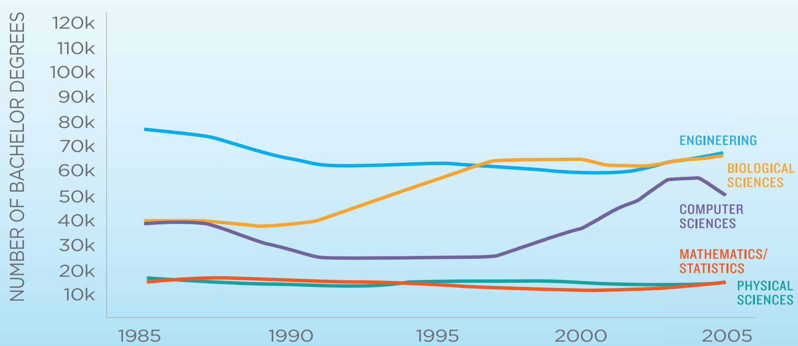
NAVY DEPENDENCE ON BACHELOR'S DEGREES

Of all the U.S. military branches, the Navy is the most dependent on bachelor's-level employees.



BUT STEM DEGREES ARE ON THE DECLINE

The Navy relies heavily on STEM skills, but fewer and fewer students are getting degrees in these fields.



MISSING GRADS

Navy security requires U.S. citizens for key positions, but 50% of doctoral graduates in these fields are foreign born.

MEETING THE NEED

STEM workers make up 35%

LOOKING TO THE FUTURE

CURRENT STEM INVESTMENTS

$80,000,000
of Navy investments in STEM education

215 programs

400+ engagements

75,000 students in Navy programs

INCREASED STRATEGIC STEM INVESTMENTS

Strategies the Navy can invest in, proven to strengthen and diversify its STEM workforce:

- Undergraduate research internships
- Freshman research initiatives
- Cognitive Tutors
- Introductory course redesign
- Student learning communities
- Scholarships for service
- Combined intervention programs

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s a dynamic portfolio of scientific research
 innovation, and the capacity to draw upon
 STEM workforce is critical to the future
Navy is anticipating 5,000 openings in its
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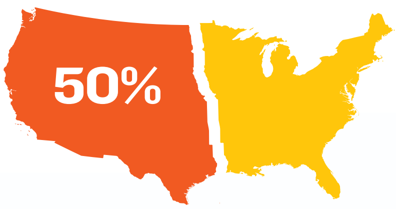
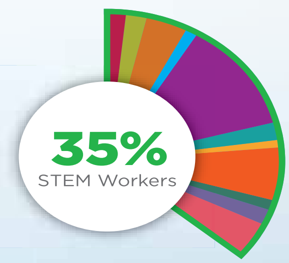
positions poses increasing challenges.



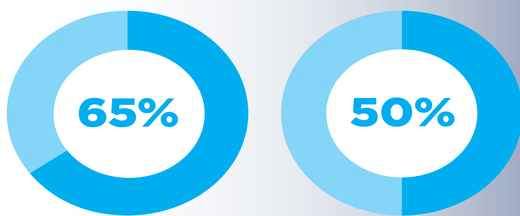
of the Navy civilian workforce.



ce Eng. - 5.0%
er Eng. - 5.5%
er Sci. - 10.5%
l Eng. - 3.2%
cs Eng. - 33.8%
Eng. - 4.8%
Mathematics - 2.5%
Mechanical Eng. - 16.4%
Ops Research - 2.5%
Physics - 4.5%
Other - 11.2%

AGING ENGINEERS

65% of Navy STEM professionals are 40 or older. 50% will be eligible for retirement by 2020.



LEAVING A GAP OF 5000 NAVY STEM WORKERS

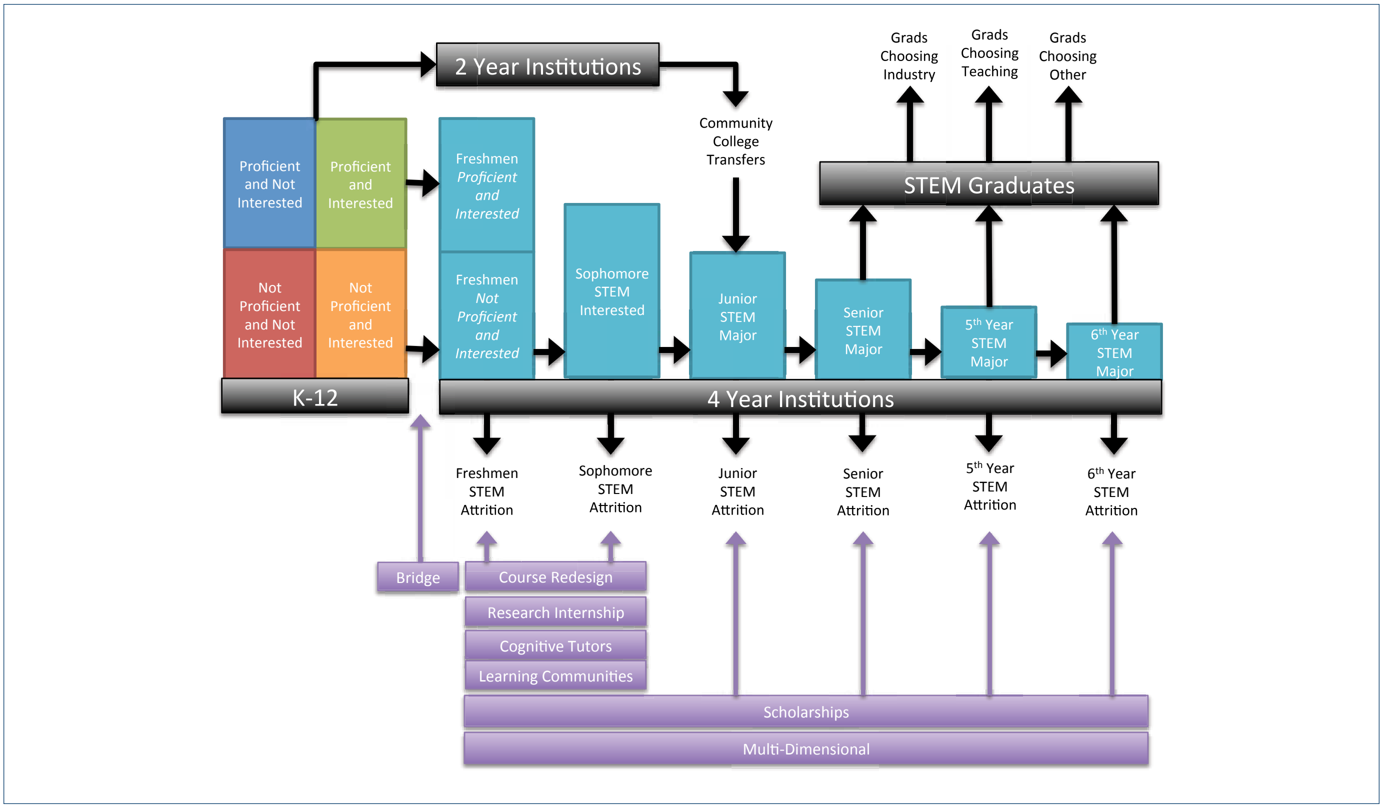
= 50 STEM WORKERS

VERSITY

ile Latinos and African Americans are the
est growing demographic, they are the
t engaged in STEM professions

men are significantly under represented in
EM professions like math and science

Simplified Representation of BHEF U.S. STEM Education Model



The model structure enables users to track the flow of students as they move through the K-12 school system, into postsecondary education, and into STEM industry and teaching careers. In elementary school, students are determined to be either STEM proficient or not STEM proficient, based on data from the National Assessment of Educational Progress (NAEP), the mathematics scores from which serve as a proxy for STEM proficiency. When students enter secondary school, the model divides students into four streams based on mathematics proficiency and interest in STEM-related activities. After high school, any student who is not STEM-proficient drops out of the model because the focus of the model is on the production of STEM graduates, and there is negligible flow of these students into STEM majors. Thus, the postsecondary portion of the model includes only those students who are STEM-proficient and those students who declare STEM majors or STEM education majors. After college, the model divides students into three streams: those who choose STEM teaching careers, those who choose STEM industry careers, and those who choose non-STEM careers.

In the STEM2Stern report, the Secretary of the Navy, the Honorable Ray Mabus, committed to doubling the Navy's direct investment in STEM over five years, to more than $100 million. Recognizing the gravity of this challenge and the need for a deeper understanding of the anticipated gains from future investments, ONR engaged BHEF to apply its model of system dynamics to the Navy's STEM undergraduate education priorities. Focusing primarily on the first two years of a student's STEM experience, ONR sought a deeper understanding of the Navy-relevant, research-based interventions that could dramatically reduce STEM student attrition rates at scale, an input imperative for achieving the president's PCAST goal of one million additional STEM graduates.

In practice, the model gives users the ability to test the role of various intervention scenarios as well as validated, highly efficacious programs that combine more than one intervention, at scale, in order to increase the number of students who graduate in a STEM field. The model incorporates a variety of demographic inputs and standardized test scores to track the flow of students through the K-16 education system and into careers in STEM teaching or STEM industries. The model allows the user to understand the level of investment and commitment required to reach the president's one million goal, the types of interventions that are most efficacious, as well as the best timing for the investment, be it discrete or sustained throughout a student's entire undergraduate experience.

The New U.S. STEM Undergraduate Model

The next generation tool, the U.S. STEM Undergraduate Model, retains components of the original model, but adds significant depth in its ability to simulate interventions that can improve STEM college graduation outcomes. The model enables users to simulate various investments that can affect students as they move through STEM undergraduate programs.

A considerable body of literature strongly suggests that certain interventions during a student's first two years of college—such as opportunities for undergraduate research—can serve to keep that student engaged in STEM-related work and on a pathway to a STEM-related career. The PCAST report was strongly grounded in such research. It cited evidence, for example, that "[r]esearch experiences in the first two years increase retention of students in STEM majors and improve students' attitudes toward STEM fields." Similarly, the report also said that "[t]he effects of research experiences are quite positive for all students but have especially high impact for women and members of other groups currently underrepresented in STEM disciplines."

A considerable body of literature strongly suggests that certain interventions during a student's first two years of college—such as opportunities for undergraduate research—can serve to keep that student engaged in STEM-related work and on a pathway to a STEM-related career.

To be selected for inclusion in the model, the modeling team subjected discrete interventions to a rigorous review process to ensure that they met the following criteria:

a. The intervention had published rigorous evaluations that showed direct linkages to increased student retention rates;
b. The intervention was included in the PCAST *Engage to Excel* report as a highly efficacious practice; and
c. The intervention was relevant to past, current, or prospective Navy investments.

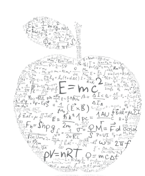
The six research-based intervention strategies that were selected to be modeled were:

1. early undergraduate research internships;
2. bridge programs;
3. student learning communities;
4. scholarships;
5. course redesign to foster active student learning; and
6. cognitive tutors.

The effect-size coefficients embedded in the model derived from a literature review that was conducted on each of the six interventions. From that research, all published coefficients linking the interventions to retention were identified; the validity and reliability of the study was ranked and weighted; and, depending on the quality of the studies, an intervention coefficient was selected. In addition, the research uncovered the discrete elements that each intervention should display to ensure the highest quality program fidelity. Where research permitted, a range of effect size was embedded in the model to reflect the minimum and maximum effect sizes based on the quality of the implementation. All coefficients and ranges were reviewed and evaluated by leading expert for those interventions.

To ensure that the model included the most up-to-date research on high-impact interventions, BHEF worked closely with intervention experts to validate the research that informs the model and the coefficients that it uses. Concerted focus ensured that the model's design replicated the effects of the best evidence-based practices. Development of the U.S. STEM Undergraduate Model was informed by a series of formal and informal meetings with a wide range of stakeholders from the Navy and other government agencies that provided invaluable specific feedback. Many suggestions from these groups have been incorporated into the design.

The structure and assumptions built into the U.S. STEM Undergraduate Model closely align with the findings of the PCAST report, using research from *Engage to Excel* to analyze interventions at scale to achieve maximum impact for increasing STEM student persistence, and focusing on the first two years of college to strengthen and diversify STEM participation and meet the president's goal of graduating one million additional students in STEM fields. Grounded firmly in sound and tested research findings, the U.S. STEM Undergraduate Model will help the Navy identify the most effective strategies for increasing the number of STEM-proficient graduates eligible for its workforce. Moreover, it will help the Navy identify agencies in both the public and private sectors with whom the Navy might partner to advance mutual goals.



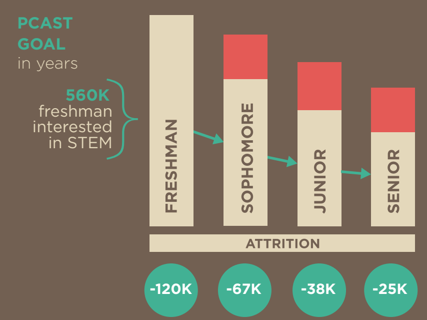
A MODEL TO SECURE AMERICA'S LEADERSHIP IN STEM FIELDS

Through its U.S. STEM Education Model® and the National Higher Education and Workforce Initiative, BHEF one of our nation's most critical challenges—increasing the number of students who pursue careers and c

In direct response to the President's call for one million additional STEM students, BHEF developed the U.S. dynamics modeling, funded by the Office of Naval Research. This Model provides an evidence-based path for increasing STEM student retention and the number of graduates entering the STEM workforce.

THE PROBLEM

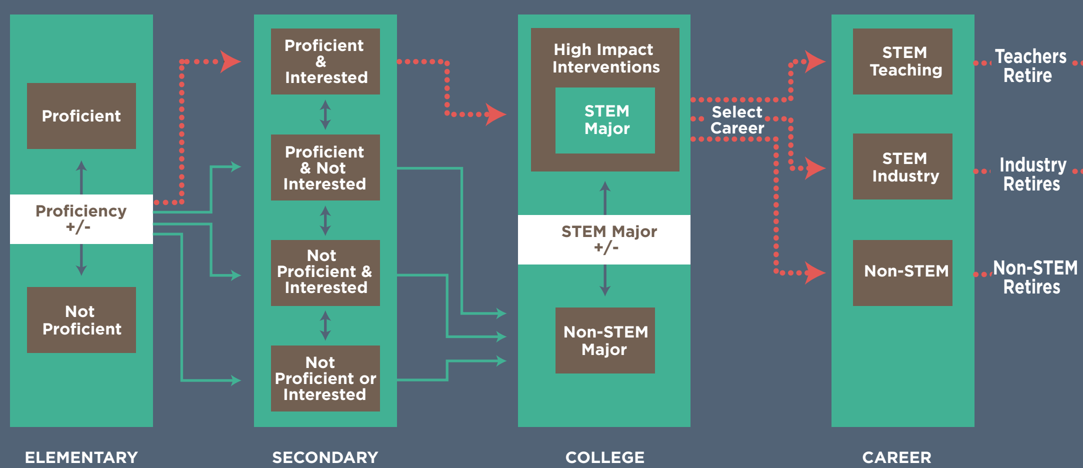
High attrition from STEM majors, especially in the freshman and sophomore years of college, vastly reduces the number of graduates with STEM degrees. High impact interventions are needed to reach the PCAST* goal of increasing STEM grads by 100k per year.



*PCAST = President's Council of Advisors on Science and Technology

THE MODEL

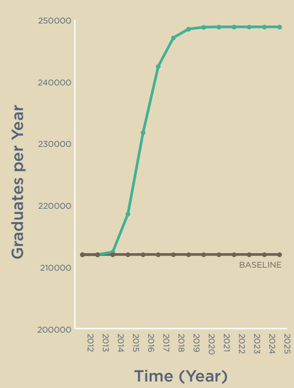
The Model captures the effects of scaling the most effective interventions for raising STEM retention.



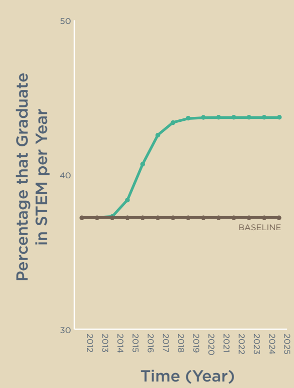
OUTPUTS

The model simulates effects of selected interventions and comparisons of interventions.

STEM GRADUATES



PERCENTAGE THAT GRADUATE in STEM



has broken new ground in developing the tools necessary to address
mplete degrees in science, technology, engineering or mathematics.

STEM Undergraduate Model, an innovative application of system
way to find, identify and scale the highest-leverage education strategies

310K
STEM capable
workforce

INSIGHTS

1. Focus interventions in the critical **first two years of STEM undergraduate education**
2. **Disruptive/systemic institutional interventions,** such as cognitive tutors can lower per-student costs and improve retention
3. A strategy of employing **blended intervention types** (i.e., student-focused and institutional) creates synergistic effects
4. Single interventions alone at reasonable scale are not enough to reach PCAST's goal, **multidimensional programs** are required

HIGH IMPACT INTERVENTIONS*

Interventions can be used to increase persistence rates.

Intervention Population x Effect Size x Scale = IMPACT

BRIDGE PROGRAMS 1.08*

COURSE RE-DESIGN 1.17

RESEARCH INTERNSHIPS 1.24

COGNITIVE TUTORS 1.32

LEARNING COMMUNITIES 1.36

SCHOLARSHIPS FOR SERVICE 1.39

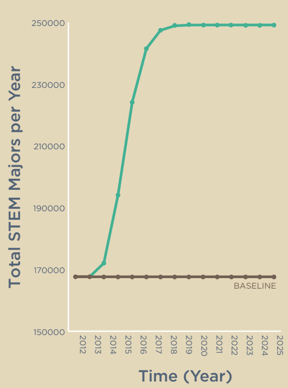
MULTIDIMENSIONAL PROGRAMS: 1.67

To simulate the effect of combinations of multiple interventions, highly successful multidimensional programs that embed at least three of the six interventions were modeled.

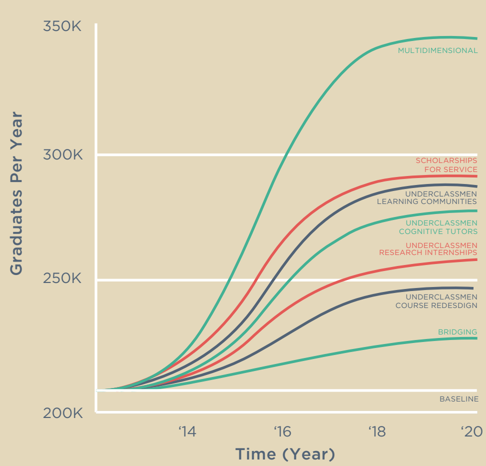
* Baseline Impact = 1.0

* The effect size embedded in the Model derived from a literature review conducted on each of the six interventions. From that research, all published effect size linking the interventions to retention were identified and the validity and reliability of the respective studies were ranked and weighted. All effect size were reviewed and evaluated by leading experts for those interventions.

TOTAL DECLARED STEM MAJORS



RESULTS: TOTAL STEM GRADUATES

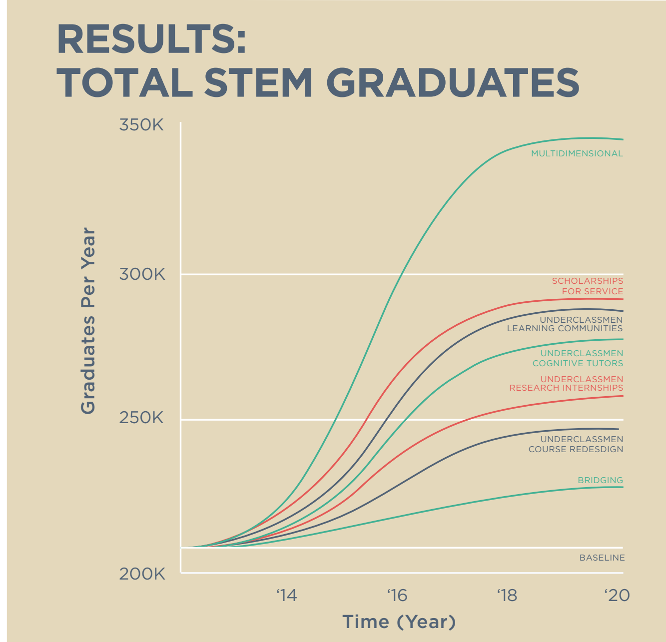


Multidimensional Programs Embed Multiple Interventions

Due to a lack of published research evaluating the additive effects of various permutations and combinations of interventions, it is not possible at this time to show the combination of the individual interventions together. In order to simulate the effect of combinations of multiple interventions, three highly successful multidimensional programs that embed at least three of the six interventions as central to the program were selected and modeled. Each of the three contains peer-reviewed evaluations of their efficacy and was included as a model program in the PCAST *Engage to Excel* report.

- **The Meyerhoff Scholars Program**. Based at the University of Maryland, Baltimore County, the program is designated for undergraduate students, with a focus on women and minority students pursuing STEM degrees. It combines financial aid, student learning communities, summer bridge programs, mentoring, personal advising, and counseling into one comprehensive program. Matched interventions include: student learning communities, course redesign to induce active engagement, summer bridge programs, and scholarships.
- **The Louis Stokes Alliances for Minority Participation**. This national program was established in 1991 by the National Science Foundation to develop strategies to increase the number of minority students who successfully complete baccalaureate degrees in STEM fields and who continue on to graduate studies in these fields. Matched interventions include: early undergraduate research internships, student learning communities, summer bridge programs, and scholarships.
- **The Freshman Research Initiative**. Based at the University of Texas, Austin, this program provides on-campus research experiences to first-year students in STEM majors. Participants are paired with faculty and peer mentors, participate in a learning community with other participants, and engage in outreach activities intended to expose K-12 students to research in STEM fields. The program is funded by the National Science Foundation and the Howard Hughes Medical Institute. Matched interventions include: early undergraduate research internships, course redesign to induce active engagement, and student learning communities.

A key takeaway from the model is that investments in multidimensional programs, combining multiple interventions, could be a game-changer.



As the model demonstrates, multidimensional programs often produce a synergistic effect, as a result of the sustained engagement with the student that surpasses the additive effect of the discrete interventions.

Intervention Research: Underpinning the Model

An overarching principle in the design of the U.S. STEM Undergraduate Model is that it is predicated on, and meticulously constructed around, the best evidence-based practices of interventions—and combinations of interventions—that make a difference in a student's progress in STEM education. Each intervention in the model was carefully vetted for inclusion based on extensive research by experts in education, systems design, and related fields to determine what interventions work and how they work best.

Given that a system dynamics model is only as good as its data, a key to the development of the U.S. STEM Undergraduate Model is understanding the processes that contribute to vetting research and the decisions that result in the selection of particular coefficients. The intervention effect coefficients are used to reduce attrition rates for each year in which the intervention is applied. First, a range of effect sizes was established for each intervention based on a comprehensive literature review. The coefficients used in the model were based on the strength of those sources. In some cases, direct measures could not be found and the coefficients were derived using intermediate effects. Finally, the coefficients were vetted by subject-matter experts. Such processes are strongest when they are not left in a static state but rather evolve to integrate new information as it becomes available; thus, the U.S. STEM Undergraduate Model has the capacity to absorb relevant new input as it becomes available.

In support of its development of the U.S. STEM Undergraduate Model for the Navy, BHEF conducted an in-depth review of studies documenting which interventions work best to support a student in advancing his or her academic career in STEM. A summary of those findings, with select excerpts from specific findings, follows here. A more comprehensive list, annotated with sources, is available at *www.bhef.com.**

Intervention: Undergraduate Research Internships
(defined as: *an inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline on or off-campus of the home institution*).

The research suggests that the following components be included in a best-practice research internship:

- **Begin research internships earlier.** Begin during freshman or sophomore year. A study found that change is most notable during sophomore year, with significantly increased retention of STEM students.
- **Increase duration of the experience.** The longer the research experience, the greater the perceived benefit. In a study, alumni perceived even one semester's experience in undergraduate research to be very beneficial.
- **A student's research internship should take place in multiple environments, including both the home institution and off-campus.** Participants working at an institution other than their regularly enrolled institution reported significantly higher mean values for such variables as clarification of a career path, skill in science writing, self-confidence, and overall evaluation of their experience. Students working at their home institution reported significantly higher mean values for skills in the interpretation of results, understanding of the research process, learning lab techniques, and performance of their supervisor.
- **Require a presentation and poster conference.** Presenting an account of the summer's work to other students and faculty and offering a poster at a conference prompted a dramatic rise in professional confidence and identity.
- **Encourage interns to return for multiple experiences.** Repeated research internships showed increasing gains.
- **Mentors are a key component to any research internship.** Research suggests that contact with faculty outside the classroom, and the development of mentoring relationships, including with minority faculty, can decrease academic isolation and contribute to positive outcomes.

Studies identify a broad range of benefits stemming from undergraduate research internships, including:

- **Development of technical, problem-solving, and presentation skills.** Interns rated such skills significantly higher at the end of the undergraduate research experience than they did at the beginning.
- **Increased interest in graduate education.** Participation in undergraduate research increases the likelihood of students' attending graduate school. Participation especially increased graduate school attendance for African-American students. Research internships also generate new interest in graduate education.
- **Students who engage in undergraduate research are more than twice as likely to graduate with a STEM degree.** Students who participate in research, including underrepresented minorities, complete their science programs in greater numbers than those who do not.
- **Increased student confidence and empowerment.** Data indicate that a research experience gives students confidence and a sense of empowerment.
- **Increased interest in STEM career and confidence in research skills.** Student's interest in a STEM career and confidence in research skills increases with a research internship.
- **Research internships increase GPA and the number of high-level science classes taken, in particular among women and minorities.** A study found that participants who took more science classes and more high-level science classes than their peers who did not participate in an internship program had a higher adjusted science GPA in their senior year.
- **Internships positively affect students' job-offer acceptance rates.** When full-time jobs are available and offered to student interns, the acceptance rate is extraordinarily high because the students have been given opportunities to experience the job.

*All references for this report are included in the Literature Review Summaries document available at *http://www.bhef.com/model-research*.

Fundamentally, the model is designed to yield important insights into the STEM human capital pipeline and the types of interventions that can improve persistence and graduation in STEM.

Intervention: Cognitive Tutors (defined as: *educational software containing an artificial intelligence component where the software tracks students' progress and challenges toward learning, tailoring feedback to their individual needs*).

The research suggests that the following components be included in a best-practice implementation of cognitive tutors:

- **Progression of problems based on student responses.** Unlike standard quizzes and tests with a set sequence of questions, cognitive tutor programs determine a progression of problems based upon students' previous responses. Subsequent problems may increase in difficulty, address weaker content areas, or decrease in difficulty depending on a student's prior performance.
- **Immediate feedback.** Cognitive tutorial software also provides immediate responses to students' answers. Timely feedback is a frequently cited effective instructional practice, as students can work to clarify content or address problems earlier.
- **Adaptable to a range of skill/knowledge levels.** College courses often enroll students with a range of backgrounds. Thus, cognitive tutors should be capable of use by students with varying knowledge levels. Cognitive tutor programs have been particularly effective with students in remedial courses.
- **Cognitive tutors supplement classroom teaching/other assignments.** Cognitive tutorial programs are most effective when integrated with course learning goals and concepts taught in classes and labs.

Studies have identified a range of benefits stemming from cognitive tutors, including:

- **Increased learning gains.** College students in science and math courses show improved ability to solve word problems and applications with regular use of cognitive tutorial software. Students in a statistics course scored an average of 18 points higher on final exams when using cognitive tutor software. Students using cognitive tutors also mastered course material at a faster pace than peers who did not utilize cognitive tutors.
- **Enhanced student engagement and satisfaction.** In a questionnaire about a particular cognitive tutorial learning experience, 48.8 percent of participants agreed or strongly agreed that they were interested in learning about word problems, and 61 percent agreed that learning was fun using the software.
- **Improved course grades.** After using a particular cognitive tutoring software for four hours, students in a remedial math course scored an average of 15 points higher on a post-test in comparison to their pre-test scores. After completing 125 problems using cognitive tutoring software, students in a college-level genetics course averaged pre-test/post-test learning gains of 18 percentage points.

Intervention: Student Learning Communities (defined as: *a demarcated group of students taking two or more classes and/or other learning experiences together, where the courses and experiences are often organized around a common theme and may require students to be involved in out-of-class activities; some learning communities include a residential component*).

The research suggests that the following components be included in a best-practice learning community:

- **Focus early in undergraduate studies.** Many learning communities are designed for first- and second-year college students. This time is critical for student engagement and concept mastery in coursework. For STEM majors in particular, the first two years are heavy with prerequisite coursework/introductory courses critical to future success in the major(s).
- **Engage students in an academic and/or residential community.** A learning community should serve to connect students with a supportive community of peers, faculty, and staff. This community can serve as both an academic resource and a social outlet.
- **Involve faculty members as collaborators.** Faculty teaching courses associated with learning communities create a cohesive learning experience by planning course topics and projects together. Often, at least one faculty member resides with students in a community to help link academic and extracurricular elements of the programs.
- **Facilitate cognitive development.** Enable students to connect material, concepts, ideas, and skills across courses.

Studies have identified a broad range of benefits stemming from learning communities, including:

- **Retention.** Learning communities have a number of indirect, positive effects on student persistence. By facilitating frequent faculty-student contact, peer interactions, and academic engagement, learning communities provide conditions that lead to increased student persistence. Learning community students have greater first-year retention rates than their peers in traditional coursework. Learning communities have a positive effect on persistence among STEM majors specifically.
- **GPA.** Controlling for SAT scores and other pre-college variables, students involved in learning communities report higher GPAs than students in traditional courses. Women in STEM living-learning communities also earned higher GPAs than peers in other programs.
- **Satisfaction with college.** Students involved in learning communities report greater satisfaction with their experiences in college than their peers. Women in STEM living-learning communities reported a stronger sense of belonging to their college or university in comparison to students in other residential settings.
- **Increased confidence in STEM courses and careers.** Women in STEM living-learning communities expressed feeling more confident in their math and engineering courses and greater confidence in their future professional success in comparison to their counterparts living in traditional residence halls.

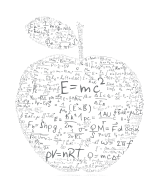
Intervention: Bridge Programs (defined as: *a cohort-style series of courses, activities, and learning experiences intended to help students make a smooth transition from high school to college, typically taking place the summer prior to the freshman year*).

The research suggests that the following components be included in a best-practice bridge program:

- **Ongoing contact with students.** The advising and support provided to students during bridge programs should be continued during the freshman year and beyond. This can be accomplished through agreements with academic departments, mandatory advising for bridge participants, and extended programming.
- **Exposure to rigorous college-level coursework.** Summer bridge courses that mirror the workload, pace, and expectations of introductory STEM courses prepare students for the rigors of a full-time course load. Such programs help students to develop study habits and skills that will help them succeed in coursework for their respective majors.
- **Clustered course registration.** The benefits of peer networks developed during bridge programs can be extended by clustering bridge students in designated sections of introductory science and math courses during the fall and spring semesters. This will enable bridge students to study together and support one another in courses that may otherwise be intimidating and isolating.
- **Introduction to resources.** Bridge participants benefit from exposure to campus resources to support their academic success and personal wellness. Workshops, campus tours, and guest speakers are all effective ways to expose students to campus resources.
- **Collaboration with academic departments.** Bridge programs with support from academic departments are particularly effective, as they are able to offer courses for credit toward students' majors, arrange for special registration permissions, and link students with faculty and staff in their majors.
- **Connecting students with a network of supportive peers, faculty, and staff.** Early opportunities to meet future classmates, upperclassmen, faculty in their respective departments, and support staff with a vested interest in students' success helps develop a supportive environment for incoming STEM students.

Studies have identified a broad range of benefits stemming from bridge programs, including:

- **Success in introductory courses.** Among students in developmental bridge programs, participants were 4.4 percent more likely to pass introductory math courses than their peers.
- **Increased retention.** Students who participate in summer bridge programs are retained in their majors and college overall at higher rates than their peers who do not participate in bridge programs. In a study of a mathematics bridge program, participants had 3-year retention rates 28.6 percent higher than their peers who did not participate in bridge programs.
- **GPA.** Summer bridge program participants at one university had GPAs averaging 0.5 points higher over seven semesters than their peers who did not participate in bridge programs.
- **Higher graduation rates.** Controlling for individual student characteristics, summer bridge program participants graduate at rates higher than their peers who do not.



Intervention: Course Redesign to Induce Active Engagement (defined as: *redesigning introductory courses from standard instructor-centered, lecture/homework/exam format to a student-centered format that uses interactive engagement, project-based learning, and other approaches to achieve better learning outcomes*).

The research suggests that the following components be included in best-practice course redesign:

- **Focus on redesign of introductory courses.** Less than 40 percent of undergraduates who begin college with the intention of majoring in a STEM field complete a STEM degree. Many leave these majors after taking introductory classes. Introductory courses in math and science departments are often required for STEM majors and serve as prerequisites for more advanced courses. Students report that these classes are often large lecture-style courses and perceive that they are intended to "weed out" students. Both faculty and students have frequently reported an over-reliance on lectures in these courses.
- **Encourage the use of innovative pedagogical practices.** Students benefit from pedagogical practices that extend beyond lecture to include applications of course topics, problem-based learning, collaborative/cooperative learning, and active learning. Faculty institutes and workshops have led to sustained improvements in teaching practices in introductory courses.
- **Maximize student/faculty interaction.** Small class sizes, small-group learning, and opportunities to engage in undergraduate research all provide increased opportunities for students to have positive interactions with STEM faculty. More frequent interactions with faculty lead to improved problem-solving abilities.
- **Develop spaces that facilitate student engagement.** The designs and equipment available in classroom spaces can aid instructors in delivering engaging lessons. Specifically, spaces with movable furniture can facilitate group work, and the availability of updated technology such as clickers for student responses enables instructors to actively engage students throughout their classes.
- **Shift to student-centered learning environments.** Students respond positively to lessons tailored to their individual interests, experiences, and learning styles. Students also respond to learning environments where they can contribute knowledge and instructors are not considered the sole source of information.

Studies have identified a range of benefits stemming from course redesign, including:

- **Improved student performance and satisfaction.** Small-group learning and other engaging teaching practices lead to greater academic achievement, improved attitudes toward learning, and increased persistence in STEM majors. In a study of course redesign in an introductory biology course, students in the redesigned, student-centered, Web-enhanced course scored higher on assessments than peers in traditional lecture-based courses.
- **Student gains in professional competencies.** Interaction with faculty and the use of collaborative learning practices leads to self-reported gains in students' group skills, problem-solving skills, and occupational awareness.
- **Enhanced instructor confidence and sustained improvements in teaching.** After a summer teaching institute for instructors of introductory biology courses, participants reported increased confidence in their ability to try new instructional methods in their classes, sustained changes in their pedagogical practices, and improved student performance over a two-year period.

Intervention: Scholarships for Service (defined as: *direct financial aid to students pursuing a relevant degree; upon graduation, the award recipient has a post-degree service requirement commensurate with the length of the received award*).

The research suggests that the following components be included in a best-practice scholarship for service program:

- **Financial support based upon a student's individual need and the cost of attendance.** STEM degree programs are often more costly than other majors due to differential tuition practices, laboratory fees, expenses of textbooks and materials, and extended times to degree. Thus, a student's perception of aid amounts may differ based upon their context.
- **Complements academic needs and resources available on campus.** Despite benefits of financial support, academic support remains a key element of student persistence. Corporations and agencies can provide support while students are still enrolled by partnering with universities to offer work opportunities and other resources on campus or offering summer internships that complement undergraduate coursework.
- **Lessens financial burdens on students.** Debt from student loans is negatively associated with persistence. Students of low socioeconomic status and underrepresented minority students are especially sensitive to debt from student loans and are often more reluctant to go into debt.
- **Offered early in the undergraduate program.** Financial aid during the first year of college is positively associated with degree completion.

- **Service component that provides career insight or addresses a societal need.** The service component may help students refine their interests and stay in a STEM-based career after college. Scholarships for service may also encourage students to pursue majors/careers that address societal/workforce needs.

Studies have identified a range of benefits stemming from scholarships, including:

- **Improved retention and degree completion.** Numerous studies have linked various forms of financial aid to increased student persistence.
  - *Gift aid:* Gift aid in the form of scholarships and grants has a particularly positive effect on student retention, and debt associated with student loans has a negative effect on persistence. STEM majors receiving gift aid have higher retention rates than those receiving only loans or a combination of loans and gift aid.
  - *Aid in exchange for work/service:* Working on campus, or working fewer than 14 hours per week, is also positively associated with degree completion. For students working on campus, the likelihood of completing an undergraduate degree increases 2 percent for each year of work.
  - *Need-based aid:* Scholarships have the greatest impact on degree completion when awarded to students with outstanding financial need. In contrast, in some states, after implementing state merit-aid programs, there have been only marginal increases in STEM enrollment and degree completion. Findings from another study predicted that many recipients of merit-based scholarships would have completed degrees in STEM regardless of whether they received scholarships or not.
- **Greater likelihood of pursuing graduate study.** Underrepresented minorities in STEM majors are more likely to use student loans to fund their undergraduate degrees and less likely to go into greater debt to pursue graduate degrees. Therefore, scholarships may lessen financial burdens that would deter students from furthering their education.

Numerous studies have linked various forms of financial aid to increased student persistence, including gift aid; aid in exchange for work or service; and need-based. Scholarships go furthest with underrepresented minorities in STEM majors who are less likely to go into greater debt to pursue graduate degrees.

On a practical basis, achieving this goal will require an additional 100,000 STEM graduates each year, or an increase of some 10 percent per year over the next 10 years.

System Dynamics in Practice: Insights from the U.S. STEM Undergraduate Model

The U.S. STEM Undergraduate Model is designed to pinpoint, clarify, and add understanding around interventions and strategies that can improve STEM retention in postsecondary education and ultimately increase the U.S. STEM workforce. Fundamentally, the model is designed to yield important insights into the STEM human capital pipeline and the types of interventions that can improve persistence and graduation in STEM. The tool helps decision makers understand, with evidence, their funding options and opportunities at scale. It can suggest potentially more productive avenues for investments in STEM education and can identify pathways to collaboration that may help agencies leverage their resources and efforts.

A number of key findings became apparent from running model simulations, including:

- A **focus on undergraduate education** has the highest potential return on investment in developing the STEM workforce.
- High-impact retention strategies **in the first two years of college** will have a greater effect on the STEM pipeline than interventions later in an undergraduate program.
- **Opportunities made available to students outside the university** (e.g., internships and scholarships that link funding to service) can increase STEM graduation rates.
- New teaching and learning models, such as course redesign, cognitive tutors, and intelligent courseware, offer **innovative ways to improve student learning in STEM**, which in turn improves retention and graduation.
- **Increasing persistence** will create capacity challenges in third and fourth-year courses—and the time taken to address them will lessen the impact of STEM retention programs.

Viewing the model's findings more broadly, several high-level implications come into focus:

- Reaching the PCAST goal of one million new STEM graduates will require a **large-scale disruption** of undergraduate education practices.
- **New models of engagement** with industry and universities in which students receive multiple interventions, some relatively low-cost, in freshman and sophomore years can maximize persistence and yield higher return on investment.
- Investments in interventions in the **early undergraduate years** can be targeted to the most at-risk students and the highest-demand fields—including emerging trans-disciplinary specialties such as cybersecurity and data analytics—to maximum effect.
- **Disruptive strategies**, including course redesign and intelligent course tools, and **new programs**, such as cybersecurity, offer powerful scaling opportunities.

These findings point to many key strategy options and opportunities that the Navy can incorporate into its decision matrix around undergraduate investments.

Outcomes for the Navy

The model is helping the Office of Naval Research to better understand the challenges it faces regarding future STEM workforce demands and to identify the strategies that can best increase the number of students who persist in STEM majors and graduate in STEM fields. This, in turn, aligns with the Navy's strategic interests and can directly enhance the STEM capacity of the Navy's civilian workforce.

Specifically, the model is helping the Navy to meet a range of important goals:

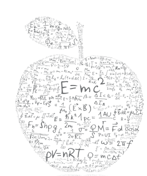
- Assist ONR in making high-leverage, evidence-based investments, of both financial support and human capital, to maximize impact;
- Engage ONR in partnerships with existing federal STEM working groups and facilitate the development of a roadmap for investments by federal agencies to jointly meet the president's goal of one million new STEM graduates;
- Demonstrate ONR's leadership in STEM and connect ONR with administration partners and those in higher education and business; and
- Encourage adoption, implementation, and research surrounding evidence-based interventions practices.

The Navy's strategies to strengthen and diversify its STEM workforce through investments in high-impact undergraduate interventions—including earlier undergraduate research internships, the development of freshman research courses, the use of cognitive tutors, the redesign of introductory courses to induce active engagement, student learning communities, and scholarships for service—align very closely with the interventions outlined in the PCAST report.

The president has called for adoption of the recommendation in the PCAST report so that the United States might produce one million additional graduates in STEM fields over the next decade. On a practical basis, achieving this goal will require an additional 100,000 STEM graduates each year, or an increase of some 10 percent per year over the next 10 years. That goal is achievable, especially if every institution that is involved in expanding STEM capacity and training commits to improve its individual outcome by 10 percent per year consistently over the next decade.

Fundamentally, the model is designed to yield important insights into the STEM human capital pipeline and the types of interventions that can improve persistence and graduation in STEM. The tool helps decision makers understand, with evidence, their funding options and opportunities at scale. It can suggest potentially more productive avenues for investments in STEM education and can identify pathways to collaboration that may help agencies leverage their resources and efforts.

A key takeaway from the model is that investments in multidimensional programs, combining multiple interventions, could be a game-changer. However, these programs are often the most costly, limiting the number of students each program can affect. To reach scale, ONR cannot solve this challenge on its own. It has taken a leadership role in demonstrating what is needed to meet the president's one million challenge but now must coordinate its efforts with other federal agencies, industry, and universities to develop and test comprehensive programs that significantly increase retention of STEM students, provide Navy relevant content, and provide a direct pipeline of Navy STEM talent. Strong partnerships are essential for providing the critical leverage needed to scale solutions for meeting the president's goals—and strengthening American capacity and competitiveness in vital STEM disciplines.



Conclusion

As this report has shown, the national challenge in science, technology, engineering, and mathematics is both real and pressing. The need for robust expertise in STEM fields is vital to maintaining the United States' security and global economic competitiveness. The imperative now is to find solutions that will help the nation meet this challenge.

The U.S. STEM Undergraduate Model developed by BHEF in partnership with the Office of Naval Research is one such solution. As this report shows, the model demonstrates the efficacy of actionable, data-driven strategies to meet the national STEM challenge. Indeed, the model represents a ground-breaking tool that offers deep insights for understanding the complex factors that lead students to successfully pursue careers in STEM-related fields—insights that can inform strategic improvements in STEM degree production.

As the report documents, the model directly shows that throughout the U.S. STEM K-16 pipeline, a focus on undergraduate education has the highest potential return on investment in developing the STEM workforce, and that high-impact retention strategies in the first two years of college will have a greater effect on the STEM pipeline than interventions later in students' academic careers. Viewing the model's findings more broadly, several high-level implications show that reaching the PCAST goal of one million new STEM graduates will require a large-scale disruption of undergraduate education practices. This will need to include new models of engagement where students receive a combination of interventions to dramatically affect retention, and institutions should focus on the development of multidimensional programs rather than interventions in isolation. Meeting President Obama's goal of producing one million additional graduates in STEM fields over the next decade is achievable, especially if institutions approach this challenge as an increase in degree completion by 10 percentage points per year.

For the Navy, insights from the model show how ONR's investments in cutting-edge STEM student retention strategies can have the strongest impact on the Navy's future workforce needs. Insights from the model complement work conducted as part of the Navy's STEM2Stern initiative, a comprehensive strategy designed to create a "one Navy" approach to STEM and to better leverage Navy resources and maximize the impact of its STEM investments.

To reach the president's goal, however, ONR cannot address this challenge on its own. If the United States is to definitively meet the STEM challenge, it is essential that federal agencies, business and industry, and higher education collaborate to develop and test comprehensive programs that significantly increase retention and graduation of students in STEM disciplines. Strong partnerships among these key stakeholders will provide the critical leverage needed to scale solutions for meeting the President's goals—and strengthening American capacity and competitiveness in STEM.

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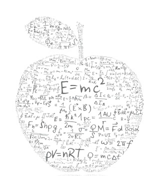

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