BHEF BUSINESS-HIGHER EDUCATION FORUM®

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Increasing the Number of STEM Graduates:

Insights from the U.S. STEM Education & Modeling Project

FOREWORD

The BHEF U.S. STEM Education Model (the Model) is the centerpiece of the Business-Higher Education Forum's (BHEF) STEM Education & Modeling Project, which is designed to help increase the number of students who pursue majors and careers in the fields of science, technology, engineering, and mathematics (the disciplines collectively known as STEM). The project's impetus is the organization's Securing America's Leadership in STEM Initiative, launched in 2005 with the goal of doubling by 2015 the number of U.S. students who graduate in STEM fields.

This report presents insights from the development and testing of the Model developed by Raytheon Company and donated to BHEF in July 2009. None of this work would be possible without Raytheon Company Chairman and CEO William H. Swanson, who currently serves as BHEF Chairman. Swanson provided the intellectual leadership for the BHEF U.S. STEM Education Model and committed thousands of training hours by Raytheon engineers led by Brian Wells and Alex Sanchez. BHEF's STEM Working Group (Appendix A), under the leadership of previous co-chairs Swanson and Warren Baker, president emeritus of California Polytechnic State University, has provided ongoing strategic guidance and advice.

These and other BHEF members lent additional support. Ohio State University (OSU) President Gordon Gee supported the participation of OSU faculty members Kathryn Sullivan and Joseph Fiksel who have been instrumental in helping to manage the Model and advance its use. With the support of former ACT CEO Richard Ferguson, staff members James Sconing and Steve Robbins led a team of ACT researchers who prepared data and research on student interest. Boeing Senior Vice President for Human Resources and Administration Richard Stephens supported the involvement of staff members Mike Richey, Paul Newton, and Mohammad Mojtahedzadeh, and Arizona State University President Michael Crow has supported the involvement of faculty member James Middleton among other faculty.

Besides these numerous in-kind contributions, the STEM Education & Modeling Project has benefited from generous financial support. In addition to support through BHEF members' dues, the modeling project has been supported by the Bill & Melinda Gates Foundation since 2008, and Northrop Grumman Corporation has provided funding to support the modeling work, generally, and to enhance the portions of the Model that pertain to teachers, in particular. The Ewing Marion Kauffman Foundation hosted the inaugural convening of the STEM Research & Modeling Network (SRMN) in 2008. The SRMN brings together researchers, policymakers, practitioners, corporations, and funders around the goal of using simulation modeling to improve STEM education and policy, and plays a central role in advancing the BHEF U.S. STEM Education Model. BHEF continues to work with these and other partners as the project evolves and welcomes interested parties to join in this innovative effort.

Finally, the STEM Education & Modeling Project has benefited from several foundational reports. The National Academies' "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future," provided baseline knowledge about the nature of the STEM problem and approaches to addressing these problems. BHEF's own reports, "A Commitment to America's Future: Responding to the Crisis in Mathematics and Science Education," and "An American Imperative: Transforming the Recruitment, Retention and Renewal of Our Nation's Mathematics and Science Teaching Workforce," provided the modelers with data and insights into the P-12 education system and an array of teacher issues. Other reports, too numerous to cite, also contributed to the modeling effort.

Executive Summary

BHEF's Securing America's Leadership in STEM Initiative has broken new ground in addressing one of our nation's most critical challenges – increasing the number of students who are interested in and pursue careers in science, technology, engineering or mathematics, the so-called "STEM" fields. The Initiative, which identified as its goal the doubling of U.S. bachelor's degrees earned in STEM fields, produced the first simulation model of STEM education in the United States.

The BHEF U.S. STEM Education Model (the Model), developed by Raytheon Company and donated to BHEF, has provided a number of powerful insights about the highest leverage points and potential strategies that can lead to increased numbers of students who are proficient in STEM fields, and who may pursue STEM careers. It has also pointed to the need for a comprehensive, national STEM education strategy that targets critical leakage points in the STEM education pipeline, and to the need for new, more sophisticated tools that can help guide policymakers and educators. Among the most significant insights from this multi-year effort are:

- **Increasing the number of STEM college graduates will require a carefully integrated (in fact, mutually reinforcing) P-12 and higher education strategy.** Focusing on improvements to pre-school through high school or to higher education alone will not result in sufficiently large increases to achieve the goal of doubling the number of STEM graduates in the next decade.
- **Improving persistence and student success in STEM undergraduate education can produce significant returns in the near term.** The Model points to the importance of strengthening the STEM undergraduate pipeline in order to produce the skilled innovation workforce needed by STEM industry, as well as a teaching workforce that has necessary content knowledge to be highly effective in teaching STEM subjects.
- **Increasing the number of STEM-capable teachers is vital to increasing the number of students who choose and succeed in STEM majors.** Modeling simulations suggest that increasing the number of teachers who are "STEM-capable" can result in increased numbers of students going into STEM fields.
- In addition to increasing student proficiency in STEM subjects, **the United States must increase students' interest in STEM majors and careers.** Both interest in a STEM career and proficiency in STEM subjects, especially mathematics, are necessary prerequisites for students to select and succeed in a STEM major. Research by ACT indicates that **fewer than one in five 12th graders have both high interest in STEM and high proficiency in mathematics**—precursors to success in STEM undergraduate programs. Indeed, the pool of 12th graders who demonstrate high proficiency in math but low interest in STEM is more than one-quarter of all 12th graders and provides fertile opportunity to enlarge the pool of students who choose and succeed in STEM majors.

These findings have immediate implications for educators, policymakers and funders. BHEF believes that the United States must continue to focus on both creating greater interest in STEM **and** increasing proficiency among all students, especially during early grades, when student interests and career aspirations take shape. Additionally, interventions should be targeted to help maintain student interest in early grades and to ensure that students take key gateway courses, such as algebra, early enough, so that they complete high school with adequate preparation for STEM undergraduate programs.

Finally, while the fundamental work of bolstering interest and proficiency among students during middle and high school years is critically important, the Model suggests that the "return" on these efforts will be years off. This highlights the near-term importance of strengthening STEM undergraduate education to meet employers' critical STEM workforce needs in the short term.

Although further work is planned to refine the Model and compare additional policies and improvement strategies aimed at increasing STEM degree production and workforce demands, the foregoing early insights have provided important lessons that offer guidance for policy development relating to major national and state education improvement efforts, including the reauthorization of the Elementary and Secondary Education Act and the America COMPETES Act, among others.

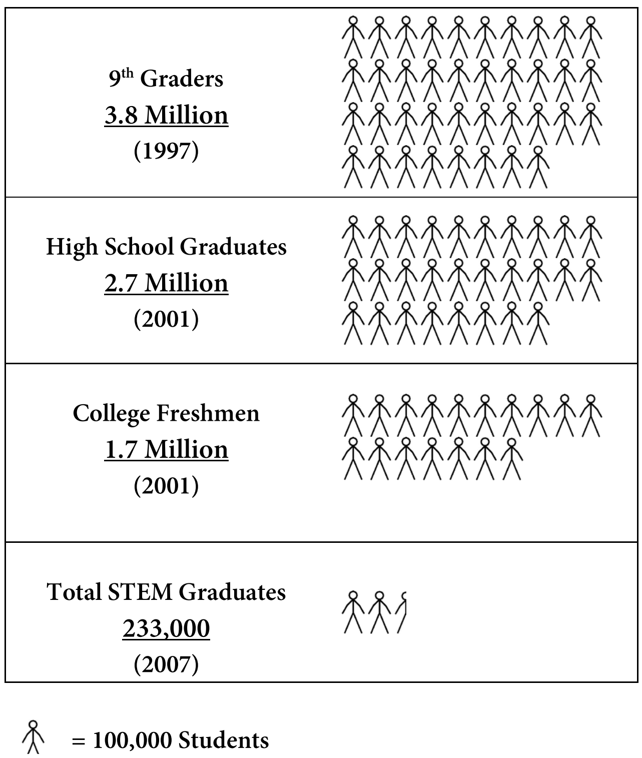
As a result of the development and testing of the Model with a broad range of stakeholders, BHEF plans to adapt the Model and extend the approach to examine other contexts and related issues. For example, based on discussions with state policymakers, BHEF and its partners, including Raytheon and Ohio State University, are launching a State STEM Education & Modeling Project that will adapt the existing national Model for use by states. BHEF has also begun discussions with a number of its members about applying the modeling approach to examine issues related to specific STEM industry and workforce demands, the role of community colleges, and challenges related to STEM graduate education, particularly at the master's level.

This approach aims to foster the development of a knowledge base that allows the diverse community of stakeholders, including policymakers, funders, and educators, to examine a range of issues and potential solutions that focus on increasing interest and proficiency among students in STEM majors and careers, as well as meet the dynamic needs of the U.S. STEM workforce.

Increasing the Number of STEM Graduates: Insights from the U.S. STEM Education & Modeling Project

Science, technology, engineering, and mathematics (STEM) are vital to American competitiveness, yet relatively few students obtain a STEM bachelor's degree (Business-Higher Education Forum, 2005, 2007). As Figure 1 shows, the STEM education pipeline narrows quickly. In 1997 there were around 3.8 million 9th graders in the United States. In 2001, about 2.7 million students graduated from high school in the same year and almost 1.7 million students enrolled in two- or four-year colleges (National Center for Education Statistics, 2006). However, by 2007 only about 233,000 students[1] earned a STEM bachelor's degree (National Science Board, 2010).

Figure 1. The U.S. STEM Education Pipeline



While the number of degrees awarded in the STEM fields[2] has increased modestly over the past five years, only 15.6 percent of bachelor's degrees were awarded in these fields, and the overall share of degrees awarded in STEM fields actually shrank during this period.[3] Meanwhile, China awarded nearly half of its first university degrees in STEM fields (46.7 percent); South Korea awarded 37.8 percent; and Germany awarded 28.1 percent.[4]

1 Includes U.S. citizens and permanent residents

2 For purposes of this paper, STEM degrees include engineering and the natural sciences, and exclude the social and behavioral sciences.

3 The number of degrees awarded to U.S. citizens and permanent residents in STEM during the period of 2003-2007 increased by 5.4 percent, however, the overall number of degrees awarded rose by 13.1 percent during the same time period. *National Science Board Science and Engineering Indicators 2010*, appendix table 2-13.

4 *National Science Board Science and Engineering Indicators 2010*, appendix table 2-35.

This relative dearth of U.S. STEM graduates led BHEF to launch its Securing America's Leadership in Science, Technology, Engineering, and Mathematics (STEM) Initiative in 2005, with the goal of doubling the number of U.S. STEM graduates by 2015. Given this ambitious goal, Raytheon Company Chairman and CEO and BHEF Chairman William H. Swanson asked, "How can we determine which ideas are most likely to be effective in increasing the number of STEM graduates?" With this charge, BHEF's STEM Working Group sought mechanisms to:

- Identify the highest leverage points and most strategic starting points.
- Ascertain the effect of scaling various policies and programs to a national level.
- Prioritize among many options to increase the number of STEM graduates.

Using System Dynamics to Meet the Challenge

In 2006, Raytheon's systems engineers took up these challenges as part of the company's Systems Engineering Technical Development Program. Through this program, teams of Raytheon engineers applied the methods of system dynamics modeling to examine the U.S. educational system.

System dynamics modeling provides a comprehensive and organized approach to help understand the behavior of a system over time. This approach allows a complex system to be deconstructed into specific components which can be examined simultaneously by the overall model. The approach can also be used to examine the effectiveness of proposed solutions in order to assist decision-makers in setting priorities and guide policy making.

Used widely in other fields, system dynamics modeling has long been helpful in studying complex dynamic systems such as the economy, climate change, and the spread of diseases. Although systems models rarely have been applied in education, lessons from other fields suggest that using this kind of analytical tool can help advance policy discussions by offering a more organized and comprehensive view of the multifaceted U.S. education system.

Benefits of System Dynamics Modeling

The use of system dynamics modeling in policy can:

- Demonstrate the capacity of the system to support the desired outcomes, often revealing unintended consequences in the process.
- Display the time lag between the implementation of a program or policy and the desired outcomes.
- Depoliticize discussions of education improvement by using systemic outcomes (i.e., increasing the number of STEM graduates in the United States), rather than specific programs or policies, as a starting point.
- Allow for examination of the relative cost associated with implementing different policies.

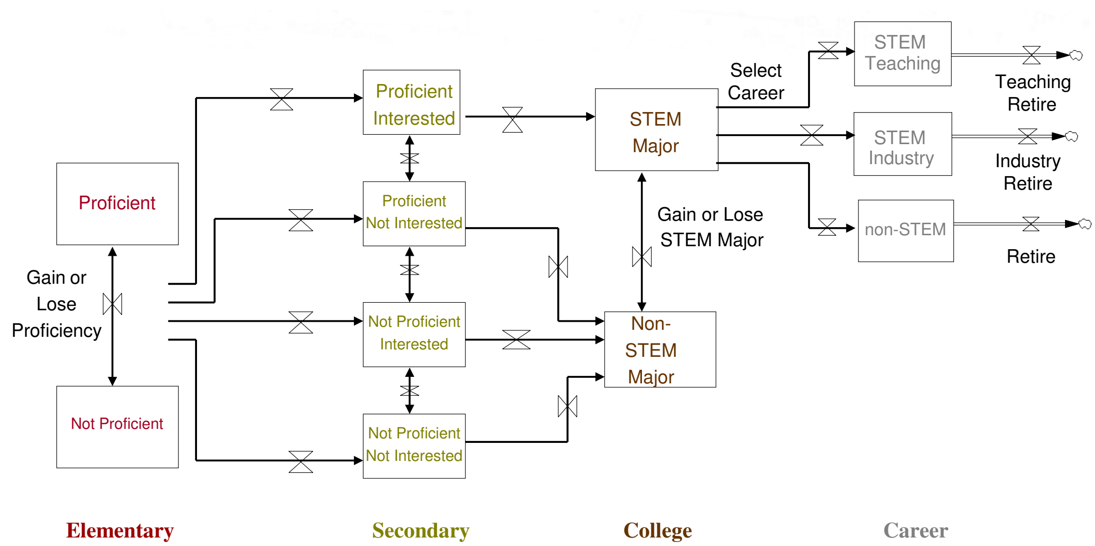
The BHEF U.S. STEM Education Model

In consultation with BHEF and other education experts, Raytheon engineers drew on national education, labor, and census datasets and conducted extensive reviews of educational research to construct the Model. As a starting point, the Raytheon team focused on areas that the research indicated as the highest leverage points related to the specific challenge of increasing the number of students who pursue and earn STEM degrees: K-12 teachers, and undergraduate STEM persistence. Focusing initially on these two areas, they developed complex algorithms, a series of dynamic hypotheses, and more than 200 unique variables to simulate and assess the impact of various STEM education proposals on the number of STEM graduates.

After three years of development, the resulting system dynamics model – the U.S. STEM Education Model (the Model) – was officially donated to BHEF in 2009. BHEF subsequently has made the Model available in open source to interested parties.

The Model structure allows users to track the flow of students as they move through the school system, into postsecondary education, and into **STEM industry and teaching careers** (Figure 2). In elementary school, students either are STEM proficient or not STEM proficient. National Assessment of Educational Progress (NAEP) mathematics scores 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.[5] 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.

Figure 2: Simplified Representation of the BHEF U.S. STEM Education Model



5 While the Model architecture differentiates students by both proficiency and interest, the data on student interest has yet to be fully integrated into the Model.

What Have We Learned?

The processes of defining the U.S. STEM education system and exploring what leads students to choose and persist in STEM majors have placed existing research in a new perspective. The development and vetting of the Model have illuminated several points that are particularly relevant in the current federal and state policy contexts, and that can be crucial to increasing the number of STEM graduates.

1. Focusing on undergraduate education yields an early and significant return on investment.

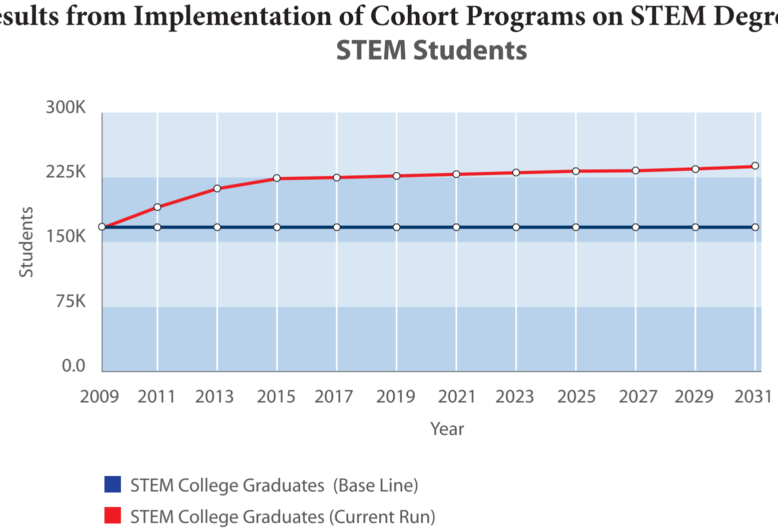
About half of the students who declare or intend to major in STEM fields ultimately leave STEM undergraduate programs and do not earn STEM degrees (National Center for Education Statistics, 2009). The first year of college is particularly important because 35 percent of STEM majors switch after their first year (Daempfle, 2002).

There exist a number of programs and strategies that have been shown to help staunch these losses, however. Among them are bridge and cohort programs. Bridge programs typically are offered in the summer between high school graduation and the first term of college and are designed to hone students' academic skills and prepare them for the rigors of college academics and life. Cohort programs build strong social networks among students by grouping them together through their course sequence, affinity dorms, and other activities.

Both types of programs have been shown to increase persistence, largely because they foster student engagement and social interaction, leading to a greater sense of connection to their programs and universities (Springer, Stanne & Donovan, 1999; Tinto, 1993; Urban Institute, 2005). Cohort programs in particular have been shown to have a positive effect on the production of STEM graduates (Nestor-Baker & Kerkor, 2009), and they have a relatively low cost of implementation, which makes them an appealing option, particularly during times of resource constraints.

The undergraduate portion of the BHEF U.S. STEM Education Model allows users to examine the impacts of bridge and cohort programs on student persistence in STEM majors, and is based on research on these programs' outcomes (Gilmer, 2007; Stuart, 2007). For example, Figure 3 demonstrates that implementation of cohort programs by 50 percent of colleges would lead to a significant increase in the number of STEM graduates in six years.

Figure 3: Results from Implementation of Cohort Programs on STEM Degree Production



Although this strategy alone does not double the number of STEM graduates, the simulations in Figure 3 show that focusing on undergraduate education has a more immediate impact on that goal than increasing the proportion of STEM-capable K-12 teachers, which is discussed in the next section.

2. STEM-capable teachers are vital to increasing STEM interest and mathematics proficiency.

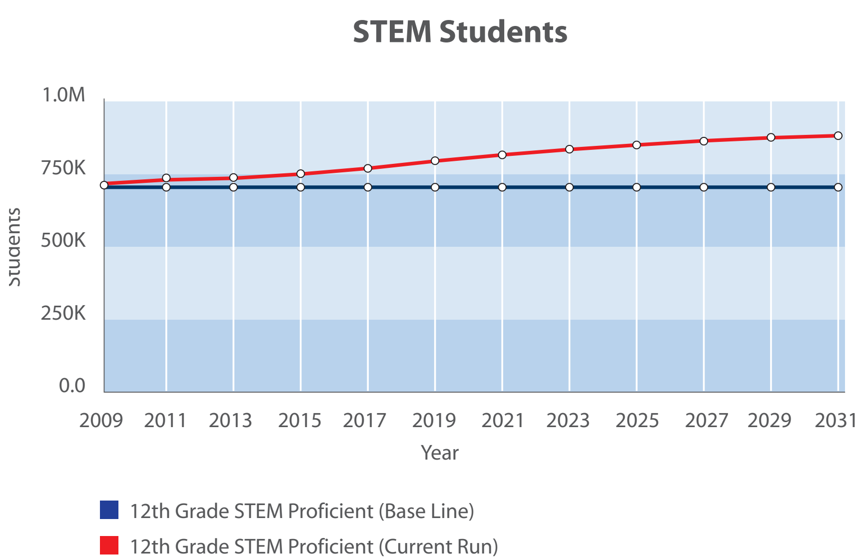
As BHEF has previously argued (BHEF, 2005, 2007), teachers play a pivotal role in increasing the number of students who are interested and proficient in science and mathematics. Accordingly, the P-12 portion of the BHEF U.S. STEM Education Model reflects the importance of teachers, and is driven by value-added research on teachers' effectiveness in increasing students' mathematics proficiency (e.g., Gordon, Kane, & Staiger, 2006; Hanushek, 2002). Specifically, the Model operates on two populations of teachers: STEM-capable and not STEM-capable, with STEM-capable teachers defined as those whose students show at least one grade level in improvement on standard math scores.

The Model's assumptions are built around two key findings related to teachers, derived from Hanushek (2002):

- Teachers account for approximately 8.5 percent of the variation in student performance during elementary and high school.
- Moving a student from a teacher in the 50th percentile to one in the 85th percentile increases a student's performance on standardized mathematics tests by 7 percent in a given year.

Simulations run with the Model suggest that increasing the number of STEM-capable teachers leads to an increase in the number of math-proficient students who declare STEM majors. Specifically, as shown in Figure 4, decreasing the attrition rates of STEM-capable high school teachers from 13 percent to 7 percent results in an increase in the number of mathematics-proficient high school students.

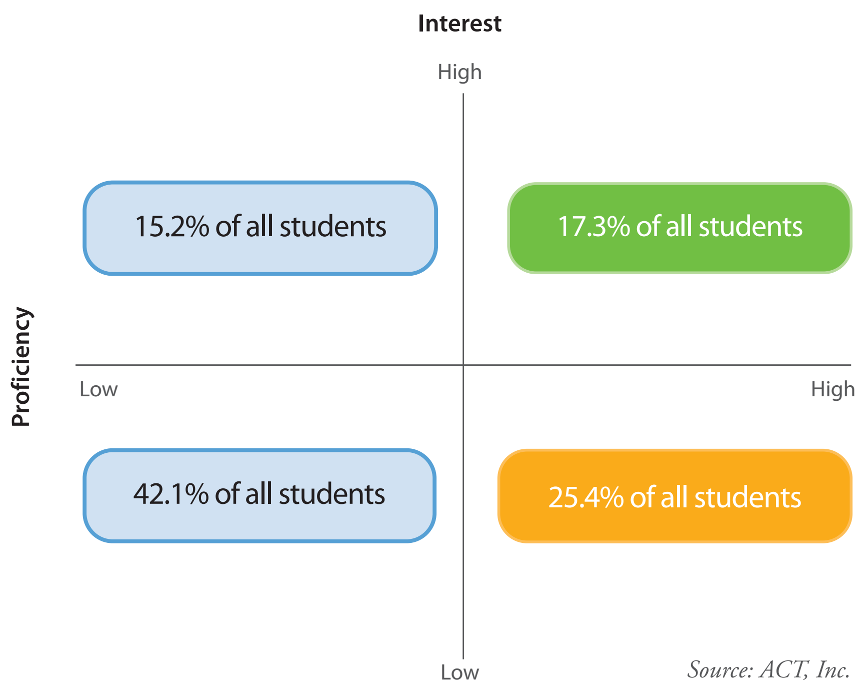
Figure 4: Results from Decreasing Attrition Rates of STEM Capable Teachers on STEM Proficient Students



3. Student interest in STEM and proficiency in mathematics are the key determinants of choosing a STEM major, yet fewer than one in five 12th graders demonstrate both high interest and proficiency.

Data from ACT show that only 17.3 percent of students are proficient in mathematics and interested in STEM (i.e., "High Proficiency" and "High Interest"), the most likely pool of candidates to pursue STEM majors and careers. Meanwhile, the largest group of students—more than 40 percent—is in the non-math proficient-non-STEM-interested category (i.e., "Low Proficiency and Low Interest"), the least likely pool of candidates to pursue STEM majors and careers (see Figure 5).

Figure 5: Distribution of STEM Interest and Mathematics Proficiency among 12th Graders



Students taking ACT test in 2008.

Looking at the remaining quadrants, it appears that targeting the quadrant "High Proficiency and Low Interest", which includes 25.4 percent of students that are math proficient but have low interest in STEM, would be a fruitful strategy because that group represents a significant population of students who could choose to opt for STEM majors and likely succeed in college.

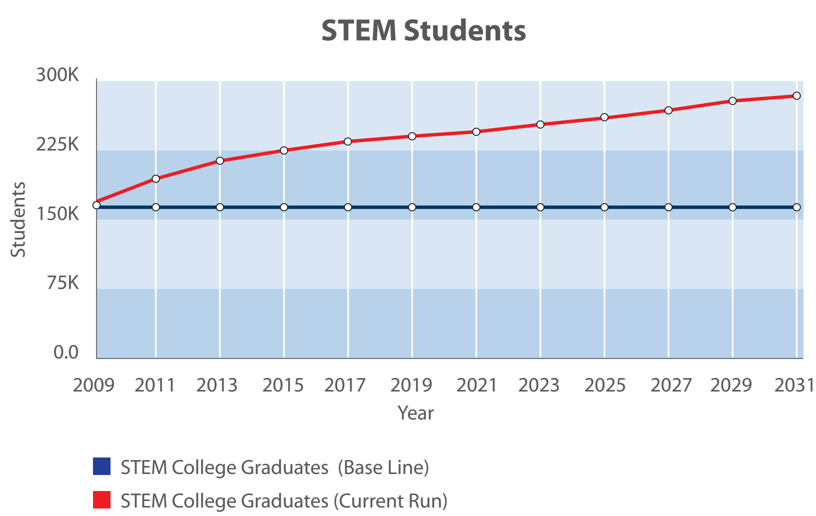
When examining data solely based on interest, ACT's data shows that only one-third of both 8th and 12th graders are interested in STEM majors and careers, a finding that underscores the importance of engaging students in activities designed to increase interest levels in STEM during the middle school years, when career awareness and interest take shape and begin to solidify.

Research conducted by ACT shows that student interest in STEM and proficiency in mathematics are independent variables. Therefore, the Model architecture was modified to incorporate separate flows for interest in STEM[6] and mathematics proficiency[7] for each gender. Interest data from ACT will be incorporated and analyzed in future versions of the Model for further insights.

4. Neither P-12 strategies nor postsecondary strategies alone are likely to double the number of STEM graduates in the near term.

Although the strategies discussed above can yield increases in the number of STEM graduates over time, no one approach alone can achieve the goal of doubling the number of STEM graduates. As seen in Figure 3, simulations run with the Model show that increasing the number of universities that offer bridge and cohort programs can yield substantial increases in the number of STEM graduates over time. Increasing the proportion of STEM-capable teachers in high school also has a noticeable effect—albeit smaller and more delayed—on the number of STEM graduates (see Figure 4). Although these two strategies are not related to each other, the Model shows that only when they are implemented at the same time does the number of STEM college graduates begin to approach the doubling goal; however it would take 20 years to achieve this result (Figure 6).

Figure 6: Results of Combining both K-12 and Higher Education Strategies on STEM Degree Production



Findings from the U.S. STEM Education Model illustrate the time lag between implementing various programs and the desired impact of increasing the number of STEM graduates. In addition, focusing on a goal, for example, increasing the relative proportion of STEM-capable teachers as opposed to a specific mechanism for achieving that goal (i.e., linking tenure to performance) can depoliticize discussions of potentially contentious topics such as teacher tenure.

6 As defined by ACT college readiness cutoff scores for purposes of this paper's analysis.
7 As defined by ACT college readiness cutoff scores for purposes of this paper's analysis.

Recommendations

- The federal government, states and other funders should craft a carefully integrated and mutually reinforcing P-12 and higher education STEM strategy. Focusing on improvements to pre-school through high school or to higher education, alone, will not result in sufficiently large increases to double the number of STEM graduates.

- Colleges and universities, with support from federal agencies like National Science Foundation (NSF), states and other funders, and employers, should focus on implementing strategies that increase persistence and student success in STEM undergraduate majors. The Model highlights the near-term importance of strengthening STEM undergraduate education as the highest leverage strategy to meet employers' critical STEM workforce needs in the short-term. It also points to the importance of scaling up strategies such as cohort programs as a highly effective way to increase student persistence in STEM majors.

- The federal government and stakeholders from higher education and schools must work together to increase the number of STEM-capable teachers. Modeling simulations suggest that increasing the number of teachers who are "STEM-capable" can result in increased numbers of students going into STEM fields.

- All stakeholders must work together to increase students' interest in STEM majors and careers. A focus on increasing the pool of students who demonstrate high proficiency in math but low interest in STEM provides fertile opportunity to enlarge the pool of students who choose and succeed in STEM majors. Interventions should be targeted to help maintain student interest in early grades and ensure that students take key gateway courses such as algebra early enough, so that they complete high school with adequate preparation for STEM undergraduate programs.

Conclusion

Even in its earliest stages, BHEF's STEM Education & Modeling Project has yielded important insights that inform key federal and state education policy conversations. As the Elementary and Secondary Education Act and the America COMPETES Act undergo reauthorization, and as more states begin to formulate state STEM education reform strategies, the Model provides a number of insights that can help decision makers consider a broad range of interconnected factors related to increasing the number of STEM graduates.

To this end, BHEF and its partners are building awareness of the U.S. STEM Education Model and the use of modeling and simulation among policymakers, educators, and funders. The process of vetting the existing national Model with policymakers has resulted in requests for state-level models that can address specific state-level conditions and strategies, including the connection between STEM education and state workforce needs. BHEF and its partners Raytheon Company and The Ohio State University are launching a State STEM Education Modeling Project to address these needs. In addition, BHEF and its colleagues are continuing to refine and adapt the existing U.S. STEM Education Model in order to explore additional issues such as:

- The role of two-year colleges in meeting STEM workforce and U.S. education attainment goals.
- The impact of various approaches to recruiting and retaining STEM-capable teachers, and the impact of teacher layoffs.
- The connection between mathematics proficiency and STEM interest.
- Those interventions that can likely have the greatest impact on boosting STEM persistence at the undergraduate levels.
- Industry specific workforce needs and approaches to strengthening their education programming and outreach activities.
- How the type of training offered at the graduate level in STEM fields can better be aligned with the needs of industry, government, and other non-academic employers.

Together, these activities will assist policymakers, educators and business leaders in making better informed decisions that can help ensure a robust P-20 STEM education system and a highly skilled and innovative STEM workforce.

To learn more about BHEF's STEM Education & Modeling Project or the BHEF U.S. STEM Education Model, contact BHEF Deputy Director Chris Roe at Chris.Roe@bhef.com.

The BHEF U.S. STEM Education Model is available in open source for use by the public through www.STEMnetwork.org and is managed by a partnership among BHEF, Raytheon Company, and The Ohio State University's Battelle Center for Mathematics and Science Education Policy.

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Appendix A

SECURING AMERICA'S LEADERSHIP IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) INITIATIVE

Working Group 2010

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The Business-Higher Education Forum

BHEF is an organization of Fortune 500 CEOs, prominent college and university presidents, and foundation leaders working to advance innovative solutions to our nation's education challenges in order to enhance U.S. competitiveness. BHEF addresses education issues fundamental to our nation's ability to compete globally with two major initiatives:

- **The Securing America's Leadership in Science, Technology, Engineering, and Mathematics (STEM) Initiative**, promoting America's leadership in STEM.
- **The College Readiness, Access, and Success Initiative (CRI)**, addressing college/work readiness and success.

BHEF and its members work to influence public policy and inspire other corporate, academic, and foundation leaders to act. BHEF also conducts research to create solutions and to identify strategies and policy reforms that the organization and its members advance directly and with partner organizations.

For information on:

- The BHEF U.S. STEM Education Model, see **www.stemnetwork.org**
- The STEM and CRI Initiatives, go to **www.bhef.com/solutions**
- Research and BHEF publications, including, *"An American Imperative: Transforming the Recruitment, Renewal, and Retention of our Nation's Mathematics and Science Teaching Workforce,"* go to **www.bhef.com/publications**
- How to make a positive impact on, and invest wisely in, the pre-school through graduate school pipeline, go to **www.strategicedsolutions.org**®

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