Can a Merit-Based Scholarship Program Increase Science and Engineering Baccalaureates?

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The purpose of this paper is to investigate the following question: To what extent would a nationally competitive scholarship program increase science, technology, engineering, or mathematics (STEM) degree awards to our "best and brightest"? This inquiry is prompted by a 2006 report of a National Academy of Sciences (NAS) panel, "Rising Above the Gathering Storm," which proposed a national STEM scholarship program to improve United States competitiveness. Using the Department of Education National Education Longitudinal Study of 1988 (NELS-88), high school graduates from the class of 1992 who would potentially win such a scholarship were identified using ACT/SAT/AP test scores, grade point averages (GPA) and class standing, high school classes completed, and science fair participation. NELS-88 college transcript data indicated a lower bound estimate of between 60% to 80% of students likely to win the merit scholarships are already completing STEM degrees.

The purpose of this paper is to investigate the following question: To what extent would a nationally competitive scholarship program increase science, technology, engineering, or mathematics (STEM)[1] degree awards to our "best and brightest"? This inquiry is prompted by a 2006 report of a National Academy of Sciences (NAS) panel, "Rising Above the Gathering Storm," which proposed to improve the competitive position of the United States in the 21st century by increasing the number of top-notch students who complete degrees in science and engineering. In January 2006, four U.S. Senators introduced three

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bills, collectively titled the Protecting America's Competitive Edge (PACE) Act. The PACE Act implements 20 recommendations of the NAS report, including a proposal to fund 25,000 new competitive merit-based STEM undergraduate scholarships.

There are at least two ways such a program could be effective in increasing the number of highly qualified students completing STEM degrees. First, competition for these scholarships could increase general interest in science and engineering by sending the message that the nation judges study in these fields to be essential to national interest. This message could cause students other than those selected for scholarships to complete a STEM degree when, without it, they might not have.[2]

A second way a major scholarship program could increase the number of U.S. students earning STEM degrees is by its direct effect on the students actually winning the scholarships. Because the scholarships would be awarded to high-ability students, it is likely many, or possibly most, of the winners would have earned STEM degrees without this proposed new scholarship program. It is this second question this paper addresses.

This paper is organized as follows. The next section discusses the characteristics of students who would likely win merit-based PACE scholarships. Using longitudinal data from the Department of Education National Education Longitudinal Study of 1988 (NELS-88), we then identify 1992 high school seniors who have these characteristics. This group represents hypothetical 1992 PACE winners had the program been in existence. NELS-88 college transcript data allows one to identify how many of these hypothetical 1992 PACE winners completed STEM degrees by the year 2000. Our analysis estimates a lower bound of between 60% to 80% of students likely to win PACE scholarships would complete STEM degrees without the program.

Who Would Win PACE Scholarships?

A number of criteria could be used to determine winners.

Mathematics/Science Aptitude

To win one of these scholarships, a student would have to score very high on some test of aptitude for and/or knowledge of mathematics and science. Numerous studies have shown strong mathematics preparation in high school is highly predictive of success in college, especially success in STEM fields (see, e.g., Adelman, 1999; Fiorito & Dauffenbach, 1982; Leslie & Oaxaca, 1991; Reis & Park, 2001; Xie & Shauman, 2003). The NAS panel and PACE suggest the use of a test to determine winners. It is not clear whether a new test would be developed for this purpose. It seems likely that some of the existing tests already in wide use, such as the SAT-I test, the SAT-II subject tests in STEM fields, or Advanced Placement (AP) tests in STEM fields would be used.

High School Curriculum/Grade Point Average (GPA)

Highly selective colleges and universities typically require several other indicators of merit in addition to test scores: They look for students who completed a rigorous curriculum in high school and who earned high grades in these demanding courses. It would be relatively easy for the PACE scholarship competition to determine whether the applicants have participated in a rigorous high school curriculum and to judge how well they mastered that curriculum by using grades or class rank.

Mathematics/Science Interest

It is reasonable to assume that students with an interest in science and engineering would be more likely than other students to enter the competition. A top student who can excel in all courses in high school but who does not particularly like math or science may be thinking of a major in a non-STEM field for his or her college years and thus would be less likely to apply for these scholarships.

Other Considerations

Selective colleges and universities also typically use student essays and letters of recommendation to help select the top students from among their applicants. However, it would not be practical or advisable for a national scholarship program of the magnitude proposed to require and process letters of recommendation and student essays. For example, writing ability can be measured using the essay portions of the SAT-I and the SAT-II exams that already exist. Any effort to improve on these with a special essay for the scholarship competition would be very cumbersome and expensive, given that 100,000 or more students could apply for a scholarship program such as this.

Letters of reference also would be difficult to process. Although they can give special insights, the potential number of such letters would far exceed the number of letters processed by any university. Furthermore, the value of letters of reference to selective colleges and universities is enhanced by familiarity with many of the letter writers who have recommended students who performed well in the past. In a government-funded, national competition, it would probably be necessary to treat all letter writers equally. Doing otherwise might be unfair to students attending schools with relatively few high-performing students. This would reduce the value of letters of recommendation as an instrument to discriminate among students with high grades and test scores.

Political pressures may shift PACE away from a narrow merit-based program. For example, PACE could be altered such that scholarship awards also consider demographic, socioeconomic, and regional representation. For the purposes of this paper, we assume the program will be based on merit alone.

Using NELS-88 to Identify Hypothetical PACE Winners

The U.S. Department of Education designed and implemented the NELS-88 in such a way that it would be useful to follow the education and early work careers of high school students in the class of 1992. The data file used for this study contained 10,310 records representing approximately 3.1 million individuals in 2000. Unlike surveys that are confined to college students, NELS-88 allows us to estimate how many of the most talented high school graduates did not graduate with a bachelor's degree, as well as determine the field of study for those who did complete the bachelor's. NELS-88 data on high school and college grades, test scores, course, and degree completion were taken from official transcripts rather than self-reports by survey respondents.

Two issues related to simulating PACE winners in 1992 had the program existed are: What criteria should be used to measure science ability, and how rigorous should these criteria be? The previous discussion has identified three criteria: (a) test scores, (b) rigor of high school curriculum and high school GPA/class rank, and (c) interest in science. NELS-88 contains several data that measure these criteria:

1. Students with very high SAT–I or ACT test scores.
2. Students with evidence of exceptional achievement in three areas: high school grades, SAT-I/ACT test scores, and the number of math and science courses taken. All three indicate degree of readiness to excel in STEM curricula in college. Also, students who take at least 4 years of both math and science in high school may be indicating an interest in STEM fields. Thus, completion of these courses may be an indicator of both STEM knowledge and interest—something likely to characterize those who enter and win a national STEM scholarship competition.
3. Students with high SAT-I/ACT test scores, high class rank, and one of the following: relatively high score on at least one AP exam or winning a math or science fair. The AP exam scores indicate degree of mastery of college-level coursework in a math or science field, and students who do well on AP exams in STEM fields are likely to be the kind of students who would enter the PACE scholarship competition.[3] Because there were relatively few students taking the AP exams in 1992, compared with today, and some schools did not even offer AP courses, it is possible that using AP scores only would undercount potential PACE winners. Thus, we supplement the AP criterion and allow either a high AP exam and/or prize(s) won from a mathematics or science fair competition.

The proposed PACE program would have 25,000 winners, but it would be unrealistic to assume all of the best students would apply for the scholarships. However, suppose only half of the potential scholarship winners enter the competition; the groups we define should include the top 50,000 on the criteria being measured. If only one third of the top students enter the competition, then the groups we define should include the top 75,000.

We do not know how many of the very best students will apply. The number would be higher if students are not required to take additional tests and lower if the competition required the submission of SAT-II exam scores or other test scores not already taken by most of the top students. In light of this, we assume that while 100,000 or more students may apply, the winners will be a subset of an elite group of high school seniors that number somewhere between 40,000 to 75,000 nationwide.

NELS-88 only includes students from the class of 1992. Since 1992, the number of high school seniors has increased by 25%, and the number of students who show evidence of exceptional ability in math and science has increased even more. For example, the College Board Web site indicates that there have been large increases in the number of students taking AP exams and earning high scores. From 1997 to 2005, the number of students scoring 4 or higher on the May calculus exams increased by 107% for the Calculus-AB exam and by 183% for the Calculus-BC exam. From 1996 to 2005, the number of students scoring 700 or higher on the SAT-Math test increased 82% (College Board, 1996, 2005). There also have been increases in the number of high school students taking math and science courses. For example, the American Institute of Physics (2006) reports that 623,000 students took high school physics in 1990. By 2005 the number had risen to more than 1,000,000. Furthermore, the number of students taking honors physics courses in high school more than doubled over the same period, and the number taking second-year and AP physics courses increased from 31,000 to 124,000 (American Institute of Physics, 2006).

Given the substantial increase in the number of high school graduates and the even higher increase in the number of those graduates who score high on relevant tests and take difficult science courses, one can assume a standard met by only 20,000–45,000 students in 1992 would be met by as many as 40,000–75,000 students in 2006 or subsequent years.

Empirical Results

Depending on criteria and rigor, six groups of hypothetical 1992 PACE winners were identified (see Table 1). The first two groups use SAT and ACT scores alone to identify the best students. Group 1 contains only seniors who scored at least 700 on the SAT-Math and at least 550 on the SAT-Verbal (or the equivalents on the ACT; see Office of Admission Research, University of Texas, 2001). In this group, 60% earned bachelor's degrees in a STEM field, and most of the remaining students earned bachelor's in other fields, with only 10% not earning a bachelor's within 8 years of high school graduation. However, this estimate of 60% is based upon a random cross-section of Group 1 and should thus be considered a lower bound estimate (as should all of the estimates that follow). This is because the 25,000 hypothetical PACE winners from Group 1 are not a random cross-section but would likely be composed of students who meet the Group 1 criteria *and* have a strong interest in science. It is probable that greater than 60% of this latter group would complete STEM degrees in the absence of PACE.

Group 2 also uses SAT scores but requires only a 650 or higher on the SAT-Math. This less stringent definition expands the group size to 135,000. Although this is arguably insufficiently restrictive because it includes so many individuals, we note the percent graduating with STEM degrees is 58%, almost as high as the percentage in Group 1.

For a variety of reasons, the proposed scholarship competition would probably not use SAT and ACT test scores as the sole criteria. Group 3 examines the effect of further restricting Group 1 to students whose grades placed them in the top 15% of their high school class and who earned at least 8 Carnegie units in math and science in high school.[4] These restrictions reduce the group size to 26,000. This group might be thought of as the very bright seniors who applied themselves enough to earn excellent grades and also completed many math and science courses. Of this group (Group 3; see Table 1), 75% earned a bachelor's degree in a STEM field. Compared with Group 1, which was based on SAT/ACT scores only, there were slightly fewer in Group 3 who failed to earn a bachelor's of any kind by 2000 (7%

Table 1

Percentage of High-Ability 1992 High School Seniors Earning STEM Bachelor's Degrees by 2000

Description of Group	Size of Group	Percent Earning STEM Bachelor's Degree	Percent Earning Non-STEM Bachelor's Degree	Percent Earning no Bachelor's Degree
Group 1: 1992 seniors who scored very high[b] on SAT or ACT	47,000	60	30	10
Group 2: 1992 seniors who scored high[a] on SAT or ACT math tests	135,000	58	30	12
Group 3: 1992 seniors who scored very high on SAT or ACT, earned at least 8 Carnegie units in math or natural science in high school, and had class rank in top 15% or higher	26,000	75	18	7
Group 4: 1992 seniors who scored high on SAT or ACT, had class rank in the top 20%, and either scored 4 or higher on an AP test in a STEM subject or won a high school science fair award	20,000	82	9	9
Group 5: Same as Group 4 except that AP score requirement is lowered to 3 or better and SAT/ACT score is lowered to 600	28,000	79	13	8
Group 6: SAT-Math of 600 and AP score of 3 or better in a STEM subject	23,000	77	13	10
Total population: High school class of 1992, with no restrictions (includes high school dropouts)	3.1 million	14	15	71

a "High" means that the SAT math scores were 650, and/or ACT math scores were at least 27. b "Very high" means that the SAT scores were at least 550-V (verbal) and 700-M (math), and/or ACT scores were at least 22-V (English) and 31-M (math).

vs. 10%). The biggest change, however, is that the number earning non-STEM bachelor's degrees fell from 30% to only 18%.

Group 4 takes a different approach to defining the high-ability seniors. It is restricted to those who demonstrated an interest and ability in science or math by scoring a 4 or higher on an AP test in a STEM field or who won an award in a science or math fair in high school. Most earned a 4 or higher on an AP calculus test (AB or BC). However, those who scored 4 or higher on any one of the following AP tests also were included: biology, chemistry, physics, American government, microeconomics, or macroeconomics. In addition, these students have grades that placed them in the top 20% of their high school class and scored at least 650 on the SAT-Math (or 28 on the ACT-Math test). The size of this group was only 20,000 in the 1992. This is primarily because only about 25,000 students scored 4 or higher on one of the STEM AP exams. The additional restrictions on class rank and SAT-Math scores would have brought the size down to fewer than 20,000; thus, we accepted an award in a high school science or mathematics fair as a substitute for a high AP score, which increased Group 4 to 20,000. Of this group, 82% completed STEM degrees by the year 2000. Only 9% completed non-STEM bachelor's degrees. It appears that the use of AP exam scores and science fair awards helps to identify a subset of high achievers with exceptional interest and competence in math and/or science—these traits result in the highest proportion completing degrees in math and science. However, the size of Group 4 is only 20,000.

How much would the percentage completing STEM degrees fall if the criteria were made less rigorous and group size increased somewhat? Group 5 is the same as Group 4 except that the SAT-Math requirement is lowered to 600 (or 26 on ACT-Math), and the AP exam criterion is lowered to include those with scores of 3 or higher. This increases the group size to 28,000 and lowers the percent completing STEM bachelor's degrees to 79%—only a slight decline.

Group 6 is the same as Group 5 except that an AP score of 3 or more is needed—we do not substitute a science fair award for an AP score. Although this causes the group size to fall to 23,000, this more restrictive group does not have a higher percentage completing a STEM degree, but rather the percentage completing STEM degrees falls slightly to 77%. This suggests that a science fair award in high school is a useful predictor of STEM bachelor's degree completion. Further, it suggests that Group 6 is unnecessary. Group 5 is closer to the desired size and uses a relevant variable, science fair awards, that is not used in Group 6.

These findings are consistent with Lubinski and Benbow's (2006) study of mathematically precocious youth. For 13-year-old students testing in the top 1% of mathematic ability (approximately 30,000 students nationwide), Lubinski and Benbow found 62% of males and 54% of females eventually earned STEM baccalaureates. Statistics for those testing in the top 0.5% (approximately 15,000 students nationally) that earn STEM degrees are 76% of males and 61% respectively.

Marginal Cost of STEM Degrees

Depending on definition, somewhere between 60% to 82% of likely PACE winners are completing STEM degrees without the PACE program. The direct marginal impact of the program would depend on the portion of non-STEM degree recipients who would complete a STEM degree because of PACE.

Some, but not all, of the best students can be influenced to complete a STEM degree by prestigious scholarship awards. Some students simply have an unshakable interest in a non-STEM field from the outset. Among those who do begin college as STEM majors, data indicate a substantial net movement out of STEM majors into other majors. Seymour and Hewitt (1997, p. 3) indicate that from 34% to 40% of high school graduates who intend to major in STEM fields abandon their major at or prior to college enrollment and a further 35% switch out of STEM majors before their sophomore year. Seymour and Hewitt interviewed a representative sample of college students with SAT-Math scores of 650 or higher to discern why they abandoned STEM majors. They listed the top three reasons given by students: (1) lack or loss of interest in science, (2) belief that a non-STEM major holds more interest or offers a better education, and (3) poor teaching by the STEM faculty. Other reasons included a rejection of the scientist lifestyle. These kinds of dropouts will always exist, even if universities are able to improve teaching in STEM fields relative to teaching in other fields and other desirable changes occur.

Part of the reason for net movement out of STEM fields is that many of these fields (e.g., engineering, chemistry) have highly structured curricula. It is typically much easier for these majors to transfer into non-STEM majors than it is for non-STEM majors to transfer into a STEM major. When these factors are taken into account, it should be obvious there is no practical way in a free society to get all or nearly all of the best students to major in science/engineering fields.

Assume we randomly draw 25,000 students from Group 1 (see Table 1). Of this group, we would expect 15,000 (60%) to complete a STEM degree, 7,500 (30%) to complete a non-STEM degree, and the remaining 2,500 students (10%) to not complete a baccalaureate degree. Now suppose these 25,000 students were PACE scholarship recipients. We would expect the percent of STEM degrees to increase above 60% to a theoretical (but not practical) maximum of 100%.[5]

Table 2 examines this question under several assumptions:

1. *Assumption A*: Assume that one half of those who received a non-STEM degree now switch to a STEM degree. For example, Group 1 (see Table 1) indicates that 30% (7,500) of potential PACE winners are receiving degrees in non-STEM fields. If we assume that the PACE program will result in one half of these 7,500 switching to STEM degrees, the PACE program will increase total STEM degree awards by 3,750.
2. *Assumption B*: Assume that all of those who received non-STEM degrees switch to a STEM degree. For Group 1, PACE would increase STEM degrees by 7,500.
3. *Assumption C*: Assume that the PACE program would result in 90% of non-STEM degree students (including those who did not complete baccalaureate degrees) receiving STEM degrees. This assumption would result in an additional 9,000 STEM degrees from Group 1.[6]

As can be seen in Table 2, these assumptions produce additional STEM degrees on the margin in a range from 1,125 to 9,000 depending on assumption and group. From these data, we can estimate the marginal cost of producing an additional STEM degree. The PACE Act authorizes scholarships of up to \$20,000 per year for up to 4 years. Because not all scholarships will be awarded for the maximum amount and also because some students will drop out, we make the

Table 2

PACE Cost Per Marginal STEM Degree

	Increase in STEM Degrees Assumption			Marginal Cost Per STEM Degree Assumption		
Group	A	B	C	A	B	C
1	3,750	7,500	9,000	$400,000	$200,000	$166,667
2	3,750	7,500	9,450	$400,000	$200,000	$158,730
3	2,250	4,500	5,625	$666,667	$333,333	$266,667
4	1,125	2,250	4,050	$1,333,333	$666,667	$370,370
5	1,625	3,250	4,725	$923,077	$461,538	$317,460
6	1,625	3,250	5,175	$923,077	$461,538	$289,855

Note. A: One half of non-STEM graduates switch to STEM field. B: All of non-STEM Graduates switch to STEM field. C: 90% of non-STEM graduates (including those not earning bachelor's degree) earn STEM degree. Assume annual PACE scholarship = $15,000.

assumption of an average scholarship cost of $15,000 per student per year. The estimated total cost for a 25,000-student 4-year cohort is thus $1.5 billion. Using these data on additional STEM degrees and program cost, we can estimate the "marginal cost" of an additional STEM degree produced by PACE. Given these assumptions, the PACE cost of producing one additional STEM degree ranges from $1.3 million to $159,000. The unweighted average is $474,000.

Summary and Conclusion

Defining high-ability seniors using only SAT/ACT scores indicates that approximately 60% of high-ability students in the high school class of 1992 completed a STEM bachelor's degree. When the definition of high-ability students is refined to use variables such as class rank, number of math and science courses taken in high school, AP exam scores in STEM fields, and high school science fair awards, then approximately 75% to 82% of these students earned STEM bachelor's degrees, with the exact percentage depending on which of these variables are used to construct the definition. Because students who would compete for PACE scholarships would meet the high-ability criteria and also have an interest in science, these estimates should be considered lower bound estimates.

Even under the most optimistic assumptions, 25,000 PACE scholarships would have a limited marginal effect (approximately 9,450 additional STEM degrees per cohort at high cost). However, it must be remembered that these additional STEM degree recipients would be high-ability students and program benefits may well be worth the costs.

These findings suggest most of the funds proposed for PACE scholarships would go to students who would earn STEM bachelor's degrees even without the new scholarship. These findings are consistent with Dynarski's (2004) review of studies of merit aid that found, "Even the largest estimates of the effect of merit aid on schooling decisions suggest that the great majority of aid goes to . . . families whose schooling decisions are unaffected by their receipt of aid" (p. 91).

These findings indicate alternatives to PACE should be considered. For example, using the funding to expand STEM graduate fellowships, provide financial incentives for precollege students to take rigorous courses, and build STEM-specialty high school and middle school programs may provide greater returns. Recent findings by Tai, Liu, Maltese, and Fan (2006) and Lubinski and Benbow (2006) indicate early encouragement of STEM careers and early exposure to science are significant predictors of later STEM baccalaureate completion. It would be bad policy to not analyze these and other alternatives to determine the most effective avenue to increase STEM degree awards and workers.

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End Notes

[1] STEM fields include the following science disciplines: agriculture, biology, chemistry, computer and information, geology, health, mathematics, physics and astronomy, and social science. STEM also includes all engineering and engineering technology fields.

[2] The U.S. government clearly sent this message during the 1960s with the National Defense Education Act (NDEA) during the US-USSR "space race." Evidence of NDEA effectiveness remains elusive. NDEA occurred concurrently with other factors that would influence STEM awards (e.g., strong increases in research and development spending and growing demand for science and math teachers). It is impractical to isolate the effect of a single one of these elements that together undoubtedly contributed to an increase in STEM degrees.

[3] We are not assuming that the scholarship competition would be held after high school graduation when AP scores of seniors are available. However, if the scholarship uses any exam that measures the ability to solve difficult math and science problems, students who

do well on AP exams can be expected to do well on these exams as well.

[4] A Carnegie unit is a class that meets one hour, 5 times a week all year. Only 15.6% of the class of 1992 earned 8 or more Carnegie units in math or science fields (excluding social science).

[5] This analysis is based only on the direct effect of the PACE program on scholarship recipients. It is possible that a "NDEA message effect" would result in additional STEM degrees (see End Note 1).

[6] It is not known what effect PACE would have on retention. Improved retention could increase STEM degrees from nonbaccalaureate completers. While Singell (2003) finds evidence of increased retention due to financial aid, Herzog (2005) found that financial aid reduced retention for well-prepared students. Herzog suggests this is because financial aid may restrict these students to majors or institutions that are not their first choices.