A Retrospective on Undergraduate Engineering Success for Underrepresented Minority Students

GARY S. MAY
School of Electrical and Computer Engineering
Georgia Institute of Technology

DARYL E. CHUBIN
Policy and Research
National Action Council for Minorities in Engineering, Inc.

ABSTRACT

This paper examines the various factors that contribute to the success of minority students in engineering programs by exploring past and current paradigms promoting success and analyzing models for advancing the participation of members of these populations. Included is a literature review of articles, government reports, Web sites, and archives published since 1980. Student success is correlated to several indicators, including pre-college preparation, recruitment programs, admissions policies, financial assistance, academic intervention programs, and graduate school preparation and admission. This review suggests that the problem of minority underrepresentation and success in engineering is soluble given the appropriate resources and collective national "will" to propagate effective approaches.

I. INTRODUCTION

For decades, this nation has enjoyed a leadership role in development and implementation of cutting edge research and technology. The investment made in science and engineering research in industry, universities, and government laboratories has benefited the U.S. many times over in exports sold, jobs created, and productivity. However, to maintain a competitive edge in an environment of increased international competition, the nation must bring more of its resources to bear by developing a society that is better educated and can provide the technological breakthroughs needed for this new century. A diverse population of engineers and scientists is necessary in this new work force. This issue of diversity is critical since many demographic studies indicate that the ethnicity of the U.S. workforce is changing dramatically.

According to Census Bureau projections [1], non-Hispanic white males will decline as a fraction of the working age (18 to 64) population from 37 percent in 1995 to 26 percent in 2050. Over that same span, the fraction of African Americans in the workforce will increase from 12 percent to 14 percent, that of Hispanics will increase from 10 percent to 24 percent, and that of Asians will increase from four percent to nine percent (see Figure 1). The end result is that currently underrepresented groups will increase from about a quarter of the workforce to nearly half (48 percent). The current and projected need for more science, technology, engineering and mathematics (STEM) workers, coupled with the fact that women, minorities, and persons with disabilities comprise an increasing proportion of the labor pool, argue for policies, programs, and resources that support greater participation by these groups in STEM education and careers.

Recent reports by the National Science and Technology Council [1] and the Commission for the Advancement of Women and Minorities in Science, Engineering and Technology [2] have eloquently identified the perils inherent in a society characterized by ethnic, gender and socioeconomic disparity. While progress has been made over the past twenty years, the risk remains. Currently, U.S. jobs are growing fastest in areas that require knowledge and skills stemming from a strong grasp of science, engineering, and technology [3]. In some areas, particularly in computer and information technology, business leaders are warning of a critical shortage in skilled domestic workers that is threatening their ability to compete in the global marketplace [2]. The business community is not alone in its need to develop and maintain a highly skilled domestic STEM workforce. Both academia and the Federal government have a vested interest in finding ways to deepen their pools of science and technology educators and researchers.

At the same time, STEM workers remain overwhelmingly white, male, and able-bodied, and the available pool of talented women, minorities and persons with disabilities remains significantly underutilized. Ironically, if individuals from these underrepresented groups were represented in the U.S. STEM workforce in parity with their percentages in the total workforce population, this shortage would largely be filled. Thus, more than ever, the nation must cultivate the scientific and technical talents of all its citizens, not just those from groups that have traditionally worked in STEM fields.

The National Action Council for Minorities in Engineering, Inc. (NACME) was established in 1974 by a group of concerned business leaders to develop and catalyze a suite of strategies to increase the participation of underrepresented minorities in engineering. As a primary part of its core research mission, NACME has articulated the goal of documenting the various factors that contribute to the success of minority students in engineering programs. In so doing, NACME seeks to explore past and current paradigms that promote minority success in engineering and yield new models for advancing the participation of members of these populations at every phase of educational achievement.

This paper is a response to this goal. The methodology used for the compliation of this report included a thorough review of various

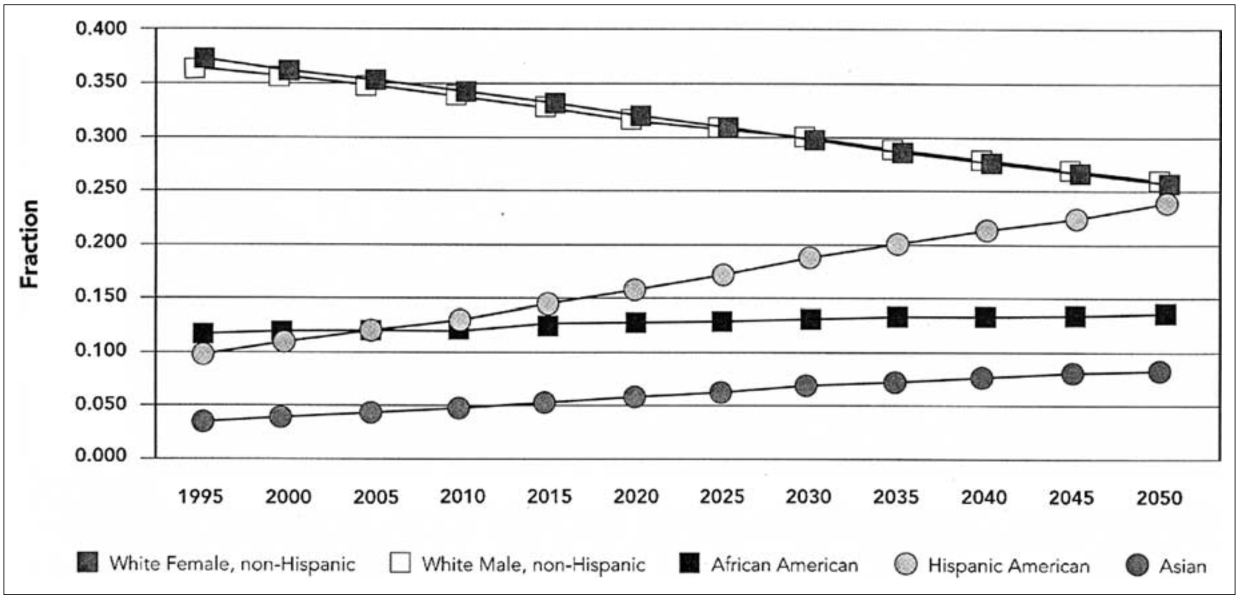

Figure 1. Population projection for ethnic and gender groups, ages 18–64, 1995–2050 [98].

articles, government reports, Web sites, and archives. The criteria used for inclusion in this literature review were a publication date after 1980, as well as the relevance of the source to minority student success in engineering and the appropriateness of the source for the topical categories selected.

The paper begins with a definition of "success" in this context. Next, an overview of the current national statistical "landscape" as it relates to the participation and success of minorities in engineering is provided. The paper then describes the factors contributing to success, correlating it to many indicators, including pre-college preparation, recruitment programs, admissions policies, financial assistance, academic intervention programs, and graduate school preparation and admission.

II. Definition of Success

"Success" can be defined in various ways, including [4]:

- spurring interest and awareness of necessary college preparatory coursework during elementary and secondary education;
- increasing opportunity for recruitment to undergraduate study;
- enhancing selection for admission; and
- providing financial assistance and intellectual support that boosts retention and ultimate completion of the baccalaureate degree.

For the purposes of this paper, the following outcome-based definition of engineering success has been adopted:

> *Satisfactory preparation for, recruitment and admission into, and completion of a baccalaureate engineering degree for members of underrepresented minority populations.*

According to the above definition, success may be correlated to many indicators, including pre-college preparation, recruitment programs, admissions policies, financial assistance, academic intervention programs, and graduate school preparation and admission. Each of these indicators were investigated and related to the engineering success of underrepresented minority students.

III. Statistical Landscape

In comparing the first National Science Foundation *Women, Minorities, and Persons with Disabilities in Science and Engineering* report of 1982 [5] with the edition for the year 2000 [6], it is clear that at least one finding has not changed—the relatively small percentages of persons from underrepresented minority populations that are earning science and engineering degrees. Figure 2 illustrates the data on bachelor's and graduate STEM degrees relative to the population as a whole, the college age population, and the S&E workforce.

To properly analyze this situation, it is first important to identify how many underrepresented students express an interest in pursuing a STEM degree. In a 1998 survey of first-year students in four-year colleges and universities, one third of white, African American, Hispanic, and American Indian students, and 43 percent of Asian students, had intentions of majoring in science and engineering [7].

Despite this level of interest, recent declines in engineering enrollment among underrepresented minority students exceed a similar decline among non-minority students. The number of underrepresented minorities enrolled as full-time first-year students in engineering declined by five percent overall from 1992 to 1996. The loss among Hispanics was less, though still troubling (a three percent drop between 1991 and 1996) [8], but African American enrollment fell by 16 percent. Although recent data from the Engineering Workforce Commission are more encouraging (African American engineering enrollment increased by more than eight percent between 1997 and 1998), it is still unclear whether the overall downward trend has been reversed. First-year enrollment in 1998 was still considerably lower than it was in 1992.

Turning briefly to graduate education, although overall graduate enrollments increased nearly four percent from 1992 to 1996, the number of graduate students in STEM degree programs has been

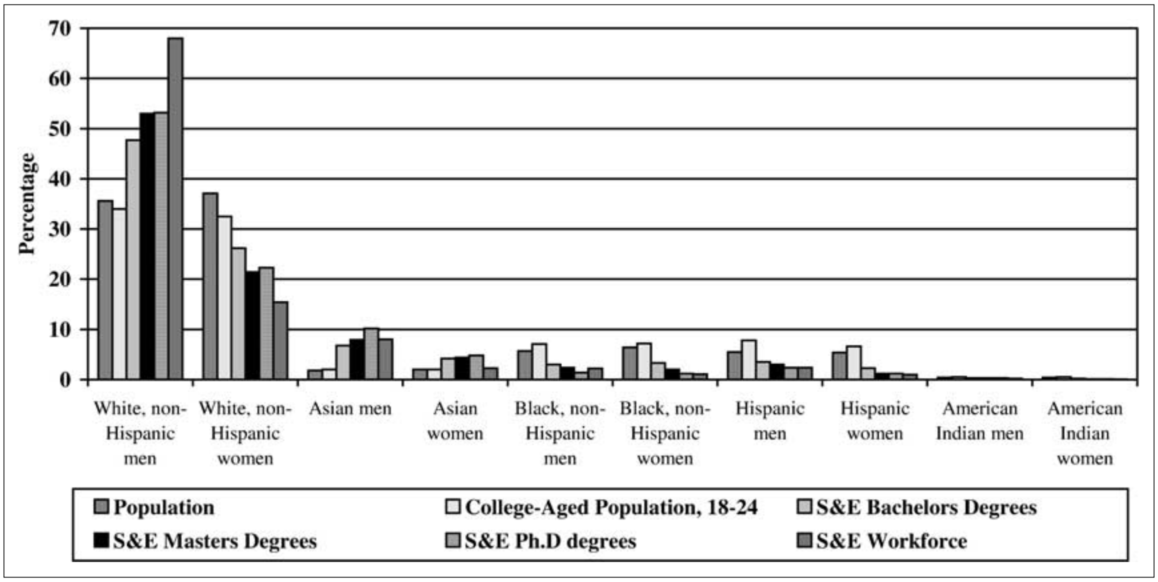

Figure 2. Percentage of population, college-age population, S&E Bachelor's degrees, S&E Masters degrees, S&E Ph.D degrees, S&E workforce, 1997 [2].

declining steadily—about two percent from 1996 to 1997, the fourth consecutive year in which a decline occurred [9]. The numbers of African American, Hispanic, American Indian, and Asian graduate students have increased since 1982. Although white STEM graduate enrollment numbers increased between 1982 and 1997, they dropped from 1993 to 1997. Once again, while the trend for minorities in STEM graduate program is positive, their numbers relative to whites are still low. For example, of all doctorates earned in STEM by U.S. citizens and permanent residents in 1998:

- African Americans earned 304 (2.5 percent);
- Hispanics earned 425 (3.5 percent); and
- American Indians earned 53 (less than one percent).

The clear message from the above analysis is that there is much work to do to achieve parity for underrepresented students in STEM fields.

	Mathematics	Science
Age 9		
Male	229	153
Female	226	147
White	236	160
African American	205	124
Hispanic American	212	129
Age 13		
Male	277	154
Female	274	147
White	286	162
African American	247	122
Hispanic American	253	128
Age 17		
Male	308	148
Female	299	145
White	315	154
African American	274	123
Hispanic American	283	128

Table 1. 2000 NAEP mathematics and science assessments.

IV. Factors Contributing to Success

Before any steps can be taken to improve the educational environment and outcomes for underrepresented engineering students, the factors that contribute to success and the barriers that impede success must be identified. As a framework for this discussion, we propose the following categories of issues: pre-college preparation, recruitment programs, admissions policies, financial assistance, academic intervention programs, and graduate school preparation and admission.

A. Pre-College Preparation

Efforts to increase the success of underrepresented students in engineering must begin with the K-12 educational system, which, to a large degree, has failed to adequately prepare these students in science, mathematics, engineering, or technology.

1) The Performance Gap: African American and Hispanic students perform well below white and Asian students in science and mathematics, the foundation for engineering success. Regardless of grade, white students outperformed both African American and Hispanic students on the 2000 National Assessment of Educational Progress (NAEP) mathematics and science assessments (Table 1). White students outperformed African American and Hispanic American students in mathematics by 24–41 scale score points. Whites outperformed African Americans and Hispanic Americans in science by 26–40 scale score points [10]. In addition, less than one-half of one percent of the underrepresented students score at the advanced level of proficiency in mathematics on NAEP [11].

Nationally, fewer African American, Hispanic and American Indian students take advanced mathematics and science courses than do white and Asian American students (Figure 3). Although underrepresented minority students are nearly 25 percent of the population, they are only 5–10 percent of AP test-takers in computer science, calculus, physics, chemistry and biology.

Finally, college entrance exam scores for historically underrepresented minority students still lag far behind the scores of white

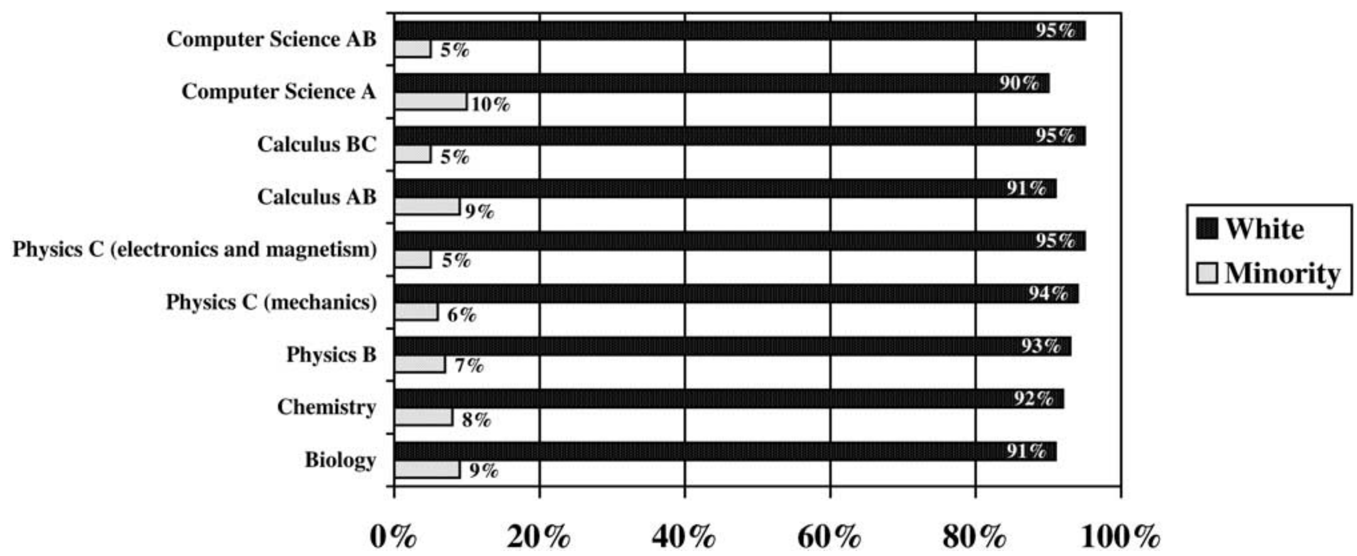

Figure 3. Advanced placement candidates, by selected subjects and race/ethnicity: 1996 [11].

	1988	1998	Difference
White	514	528	14
African American	418	426	8
Hispanic American/Latino	463	466	3
Mexican American	460	460	0
Puerto Rican	434	447	13
Total	501	512	11

Table 2. 10-Year change in average SAT mathematics scores.

students, and those differences did not change much between 1988 and 1998 (Table 2) [12].

2) The Resource Gap: Let us examine some of the reasons for the pre-college performance gap. A large proportion of African American and Hispanic students attend schools in the central city (32 percent and 25 percent, respectively). Students in these groups also tend to be enrolled in predominantly minority schools that typically suffer from a grievous lack of resources [13]. Such resources include funding, qualified teachers, high-quality curricula, and computer and Internet access [14]. Although less data are available to document the access that American Indian students have to educational resources, these students also tend to attend impoverished schools in which they are the racial majority [15].

Among all educational resources, the availability of effective teachers has been identified as perhaps the most important element in a quality science and mathematics education. Recent studies show that effective teachers help students at all achievement levels, regardless of the level of heterogeneity in their classrooms [16]. In addition, standardized test scores suggest that teacher effects on student learning are additive and cumulative over grade levels.

A large shortfall in the teacher supply is expected to materialize in this decade, resulting in a need for at least 2 million newly hired public school teachers by 2009 [17]. This overall shortage will exacerbate the already critical shortage of mathematics and science teachers. Currently, because of this shortage, many who teach mathematics and science lack adequate preparation in these subject areas. Unfortunately, a large proportion of these poorly prepared teachers can be found in schools with large numbers of underrepresented minority students (Figure 4). The result is that these students are not getting the high-quality instruction needed to succeed in the pursuit of a STEM career such as engineering.

In addition to effective and qualified teachers, educational technology such as computers, calculators, and other tools also enhance learning in mathematics and science. The U.S. Department of Commerce has coined the term "digital divide" to describe the gulf between those with and without access to new technologies. Recent data on the digital divide show that underrepresented minorities are among those most lacking in access to such resources [18].

The percentage of schools connected to the Internet has increased from 35 percent in 1994 to 95 percent in 1999. Likewise, the percentage of U.S. public school instructional classrooms connected to the Internet rose from three percent in 1994 to 63 percent in 1999 [19]. Despite this surge in Internet connections, differences remain in terms of Internet access in instructional classrooms. For example, in 1999, only 39 percent of instructional classrooms had Internet connections in schools with high concentrations of poverty (as defined by 71 percent or more students eligible for free or reduced-price lunch). In fact, no increases in Internet connections

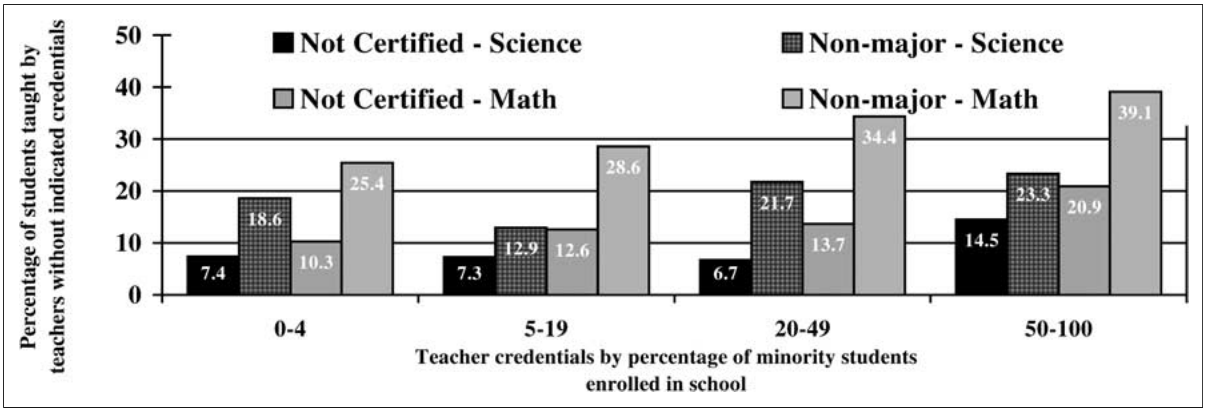

Figure 4. Public school teachers of mathematics and science without a major or certification in class subject: School Year 1993–94 [13].

were recorded in these schools from 1998 to 1999, while there were increases in schools with lower concentrations of poverty. Data also show that schools with the highest concentration of poverty had more students per instructional computer with Internet access than schools with the lowest concentration of poverty. Because schools with the highest concentrations of poverty are the ones most likely to educate low-income minority students, these students are denied equal access to learning tools important for high-quality mathematics and science education and subsequent entry into engineering.

In terms of curricular issues, secondary schools with a high minority enrollment offer less extensive and less demanding science and mathematics programs, giving minority students fewer opportunities to take the courses necessary for them to eventually pursue engineering degrees. Further, underrepresented minority students are disproportionately placed in low-level courses and thus have less access to higher-level courses even when they are in schools that offer such courses. This practice affects not only the quality, but also the number of courses that students may take. Over time, differences among tracks widen, as students who do not take prerequisite courses are excluded from more advanced classes [20].

The lack of educational resources experienced by underrepresented minority students undermines both their achievement and participation in mathematics and science. It scarcely matters whether underrepresented students of color have an interest in STEM careers. Because of inadequate preparation, low achievement levels often preclude their successfully attempting a career in any STEM field, especially engineering.

3) Programmatic Efforts: Resource limitations in the pre-college education of underrepresented minority students suggest a variety of strategies for overcoming performance gaps. Over the past two decades, these strategies have included:

- pre-college student enrichment and intervention programs [21–34];
- articles which provide advice and promote engineering preparation approaches [35–39];
- teacher effectiveness programs [40]; and
- systemic educational reform initiatives [41–44].

Targeted strategies such as these have been shown, to varying degrees, to have the potential to increase the number of underrepresented pre-college students progressing in college STEM programs [45]. In fact, an effective pre-college program should have *all* of the above elements. Specifically, an effective program must: (1) promote awareness of the engineering profession; (2) provide academic enrichment; (3) have trained and competent instructors; and (4) be supported by the educational system of the student participants (i.e., the school and/or school district).

B. Undergraduate Recruitment and Admissions

Recent declines in engineering enrollment among underrepresented minority students have a similar decline among non-minority students, and they do not seem to be associated with changes in college participation rates, smaller numbers of qualified high school graduates, decreases in the numbers of 18-year-olds, or any other demographic shifts. Instead, they may reflect a shift in the values, interests and career choices of students [46]. Given the need for skilled engineers, reasons for the decline should be vigorously explored and countered. Doing so successfully will likely require policy intervention [47–49].

1) Media Images of the Engineer: Today, nearly 70 percent of American adults say they are interested in science and technology—the highest level ever measured [2]. While more Americans than ever seem to appreciate the overall benefits of science and technology, their grasp of what scientists and engineers actually do is seriously lacking, a fact that has ramifications for how scientists and engineers themselves are perceived. Despite decades of social change, the general perception remains that scientists and engineers are unusually intelligent, socially inept, and absent-minded "geeks" or "nerds."

Advertisers, the entertainment media, and the news media have an influential role in shaping these perceptions [50]. Caricatures of (mostly white male) scientists continue to appear on billboards, in magazine ads, in movies, and on television. The scientists portrayed on Saturday morning children's television in the U.S. have been described by the late Carl Sagan as "driven by a lust for power, or gifted with a spectacular insensitivity to the feelings of others." The media portrays scientific progress as hazardous and scientists are often depicted as foolish, inept, or villainous. The news media also contribute to these distortions with stories that too often emphasize scientists and engineers as otherworldly geniuses working in isolation from society.

To make matters worse, the relative dearth of minorities in STEM careers makes it easier for the media to overlook underrepresented individuals who *are* succeeding in STEM, which only serves to perpetuate the problem. A longitudinal study conducted for the U.S. Department of Commerce found that only two percent of characters in prime time dramatic television from 1994–1998 were scientists [51]. When these researchers looked at the extent to persons from underrepresented groups were portrayed as scientists on prime time television, they found that 75 percent of the scientists were white males. One reason that minority children don't think of engineering as a career to which they can aspire is that people who look like them are so seldom portrayed as engineers or scientists, making recruitment of minority students into engineering fields all the more challenging.

One obvious strategy to counter the negative portrayal of scientists and engineers in the media is to present the opposite view. For example, in its "Math is Power" campaign, NACME presented an image on a poster of a dark, youthful hand raised in a fisted power salute, with the letters "M," "A," "T," and "H" plainly written just below the knuckles (in a manner reminscent of the character "Radio Raheem" in Spike Lee's *Do the Right Thing*). "Demand it," says the inscription over the fist, and below: "Math is power."

In a survey conducted for NACME by Louis Harris and Associates, more than 50 percent of American middle and high school children said they plan to drop mathematics as soon as the option is presented to them. Of those students who would drop mathematics, more than half were interested in careers such as engineer, computer programmer, or astronaut. NACME developed the "Math is Power" campaign to bridge the gap between the careers students say they want and the disastrous educational choices they make in the absence of a required curriculum and adequate guidance.

2) Affirmative Action and University Admissions: Even interested and adequately prepared students still face challenges in being admitted into engineering degree programs. Challenges to affirmative action policies and practices have surfaced in more than half of the states in the nation. These challenges have resulted in legislation or policies that bar the use of race in admissions decisions and financial aid awards to students at postsecondary institutions. With this anti-affirmative action movement comes an increased reliance on SAT scores as the primary selection tool for admission into undergraduate institutions [52].

In the short term, the growing challenge to affirmative action policies in postsecondary admissions has resulted in lower enrollment rates for African American, Hispanic, and American Indian students. This affects participation of these groups most significantly since STEM fields tend to be more selective. Sources of financial aid (see Section IV.C.) have also been impacted. If this trend of lowering enrollment continues, the difficulty in supplying the nation's STEM workforce will be exacerbated.

However, it must be pointed out that affirmative action programs do not represent the sole solution to counteracting enrollment reductions. For example, the Georgia Institute of Technology, an institution with race-neutral admissions policies, was the number one producer of African American engineers at all degree levels during the 1999–2000 academic year [53]. This provides evidence that approaches to admissions that rely on institutional commitment, rather than affirmative action alone, can still lead to successful outcomes.

Even as the anti-affirmative action movement has pushed some universities to rely increasingly on one-dimensional measures of academic potential such as SAT scores, NACME has developed its engineering *Vanguard* program. Recognizing that many extraordinary students from inner city schools and educationally disadvantaged backgrounds are deprived of the opportunity to develop skills measured by these one-dimensional gauges, NACME established more authentic criteria for selecting students for this program. NACME assesses content knowledge, mathematics problem-solving behaviors, and critical thinking skills by engaging students in a comprehensive, performance based assessment process. Students are taught new concepts and invited to solve complex problems, working in collaborative teams. Participating students are evaluated on their ideas, creativity and approaches to solving unfamiliar problems—exactly the competencies that make for successful engineers.

Through this interactive assessment, along with in-depth individual interviews, NACME recommends *Vanguard* scholars who might otherwise be inadmissible to participating universities. If admitted, each *Vanguard* scholar receives a full tuition and housing scholarship. Although nationally, fewer than 36 percent of the minority first-year students who enter engineering graduate with an engineering degree, student persistence in *Vanguard* averages twice that success rate, with average GPAs of 3.0. NACME has thus contradicted traditional assumptions about student potential and developed tools that are much more effective than standardized tests and grades in predicting achievement for students from widely varying backgrounds. Equally important, *Vanguard* and other similar programs [54–58] have introduced accelerated techniques that quickly develop academic competency, allowing students from non-traditional educational experiences to excel in the engineering environment.

3) The Role of Two-Year Colleges: Approximately 44 percent of all U.S. undergraduates enroll in two-year colleges. This enrollment contains a large percentage of underrepresented groups. For example, over half (54 percent and 52 percent, respectively) of Hispanic and American Indian undergraduates were enrolled in two-year colleges in 1996, and 46 percent of African Americans were enrolled in these institutions. Although relatively few students currently seek degrees in science and engineering from the two-year colleges, many of these students do in fact transfer to four-year colleges. Specifically, 26 percent of all students who begin their undergraduate careers in a two-year college transfer to four-year institutions. Of persons who earned science and engineering bachelor's degrees in 1995 and 1996, 11 percent of African Americans, 15 percent of Hispanics, and 20 percent of American Indians had earned associate's degrees [44].

Given the significant numbers of underrepresented minorities whose first experience in postsecondary education occurs at a two-year college, these institutions could potentially provide a valuable source of matriculants into engineering programs. Policies that encourage recruitment and eliminate barriers for potential transfers to four-year institutions could be especially fruitful, both for short- and long-term needs.

4) The Role of Minority-Serving Institutions: Minority-serving institutions (MSIs) also provide models of successful approaches of educating underrepresented minority students. For example, of African Americans earning bachelors degrees in STEM fields in 1996, 31 percent received them at Historically Black Colleges and Universities (HBCUs). Furthermore, a high percentage of African

Americans who go on to earn advanced degrees in science fields received their baccalaureate degrees at HBCUs [47]. Of African Americans earning doctorates in the sciences between 1975 and 1992, more than half of the biologists, slightly less than half of the physical scientists, and more than two-fifths of the mathematicians and computer scientists had baccalaureate origins in HBCUs [59].

Activities at MSIs promoted by the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) have resulted in alternative investment models at MSIs. An example of such an activity is the Minority Institutions for Excellence (MIE) program [60], which is designed to enhance the infrastructure and build the capacity HBCUs and other MSIs. By focusing on enrollment capacity and student retention, MIEs have the potential to increase the number of STEM degrees awarded to underrepresented students significantly.

5) Dual-Degree Programs: An example of a successful recruiting strategy that cannot be overlooked, the dual-degree program, builds on the success of MSIs in attracting minority students. In this model, participating students receive a bachelor's degree in liberal arts from one school and a bachelor's degree in engineering from a second institution. By joining forces in this way, the partner institutions are able to present a large pool of undergraduate (and typically minority) students with opportunities and exposure which is essential in recruiting and retention. The strength of such programs lies in the partnership and the unique strengths of each of the participating institutions.

As a case study in such programs, consider the Dual-Degree Engineering (DDE) program established by the Georgia Institute of Technology, Morehouse College, Spelman College, Clark Atlanta University, and Morris Brown College. The latter four historically black colleges and universities have offered a dual-degree program to undergraduates seeking engineering degrees since 1969. Upon completion of the program, students receive a bachelor's degree from the first school and a bachelor's degree in one of the engineering disciplines at Georgia Tech. Typically, over 100 African American students are completing B.S. degrees at Georgia Tech through this program in any given year.

The objective of the DDE program is to remedy underrepresentation in the engineering profession by providing the framework for the pursuit of a baccalaureate degree in an engineering discipline with the added benefits of a liberal arts education. Initially, the program was an agreement between Morehouse and Georgia Tech. It has expanded to include the four undergraduate institutions in the Atlanta University Center (Clark-Atlanta, Morehouse, Morris Brown, and Spelman) and other engineering institutions such as Auburn University, Boston University, Dartmouth College, North Carolina A&T State University, Rensselaer Polytechnic Institute, and Rochester Institute of Technology. Since 1974 (the year of the first DDE graduate) approximately 800 minority students have graduated from the program.

C. Financial Support

The availability of financial aid at both the undergraduate and graduate levels impacts students' decisions to enroll in post-secondary education, choose a specific major, and complete a degree [61–62]. The availability of financial aid is especially critical for underrepresented minority students, who tend to have lower incomes than white students. A recent study by NACME revealed that meeting the financial need of minority engineering students is a key factor in addressing the problem of attrition [63]. Another study by the U.S. General Accounting Office (GAO) showed that providing students with scholarship aid (as opposed to loans) has a dramatic impact on the retention of low-income students. Among students from the poorest families, a shift of just $1,000 worth of assistance from scholarship aid to a loan reduces the probability of graduation by 17 percent [46].

The rising costs of college tuition and the small amount of grant funding available to students reduce the feasibility of a college education for low-income students, many of whom are ethnic or racial minorities. This lack of affordability may be exacerbated for students in science-based programs where the time demands of coursework make employment during the academic year impractical.

The availability of financial aid and minority student access to it are crucial to increasing enrollments and degree completion in engineering. While numerous local scholarship programs have existed for many years [64–65], a national effort is clearly needed. Such an effort was initiated by NACME in the early 1980's. From 1980 to the present, NACME has financially contributed to over 10 percent of all minority engineering graduates. Overlapping this time period, the annual number of minority B.S. graduates in engineering grew from several hundred at the beginning of the 1970s to nearly 6,500 in 1998 as well [66]. However, these numbers still fall far short of parity (defined as representation approximately equal to the percentage of minorities in the population cohort).

One reason why progress has been slower than hoped is that national financial support has never met expectations. For example, a 1973 Sloan Foundation Task Force on Minority Participation in engineering called for a minimum of $36.1M per year in student financial support to reach parity in engineering enrollment by 1987. Actually funding came to about 40 percent of that figure, and as it turns out, minorities achieved about 40 percent of parity in freshman enrollment by 1987. The conclusions to be drawn are compelling: applying the same model to the present, NACME believes that by raising the retention rate to 80 percent, parity in undergraduate engineering enrollment could be achieved within six years at a cost of $370M [66].

D. Intervention Programs

Adequate financial resources are a necessary, but not sufficient, condition for minority student success in engineering. Even students with enough funding may still have a need for academic or other forms of support to ensure a productive educational environment which enables success. Before steps can be taken to improve the educational environment, however, the barriers that impede success must be identified and described. A useful framework for describing these barriers has been proposed by Astin [67], who asserted that a critical connection exists between the quality of a learning environment and the level of *student involvement*. An excellent learning environment, according to Astin, promotes a high level of student involvement, which is defined by the amount of physical and psychological energy that the student devotes to the academic experience. Astin suggested the following five metrics for measuring student involvement:

- amount of energy devoted to studying;
- amount of time spent on campus;
- amount of participation in student organizations;
- amount of interaction with faculty; and
- amount of interaction with other students.

The highly involved student devotes considerable energy to studying, spends a lot of time on campus, participates actively in student organizations, and interacts frequently with faculty members and other students. The uninvolved student, on the other hand, neglects studies, spends little time on campus, abstains from extracurricular activities, and has little contact with faculty or other students. The underlying assumption in Astin's model is that greater involvement leads to a higher probability of success.

When placed in the context of Astin's metrics for involvement, the barriers faced by underrepresented students are clear. Minority students on predominantly white campuses tend to be ethnically isolated in their classes. Given this fact and the challenges in establishing relationships across cultures, minority students tend to interact with other students less often [68]. As a consequence, these students also tend to separate their academic and social lives, and are often deprived of the benefits of sharing information and group study with peers.

Minority engineering students are also less likely to interact with faculty than non-minority students. This poses another serious barrier, since faculty-student interaction is one of the most significant factors affecting student retention [69–72]. Minority students often report that faculty send them messages (whether intentional or not) that they do not have the same expectations of success for them as they do for other students [73]. For instance, a study of graduate students at UC-Berkeley found that four of nine white students felt that faculty interaction had frequently inspired them to excel academically, while only one in nine minority students reported such experiences [74]. In addition, due to the dearth of minority engineering faculty, minority students are also deprived of the psychological benefit of role models with whom they share common ethnic and cultural backgrounds.

Although a review of the literature does not provide any studies comparing participation in student organizations and time spent on campus for minority students and non-minority students, there are reasons to suspect that the amount of involvement may be less for minority students in both cases. If minority students have less interaction with students and faculty, it seems reasonable to assume that they would be less likely to be involved in organizations having predominantly non-minority membership. Minority students are also likely to spend less time on campus because financial needs or obligations to family may reduce the amount of time spent on campus.

1) The MEP Model: Given the barriers to learning for minority engineering students, designing intervention programs to remove those obstacles is necessary to ensure success. One approach to doing so is to design a program so that it promotes a high level of student involvement as measured by Astin's metrics. That is, an effective program would increase minority students' time and energy devoted to studying, time spent on campus, interaction with other students, interaction with faculty, and participation in student organizations.

The California Minority Engineering Program (MEP) is an example of such a program [75–76]. Initiated through faculty effort at California State University, Northridge in 1973, the MEP model has been propagated for nearly thirty years, and has been successfully replicated at over 100 universities and privately sponsored programs [77–87]. Endorsed by NACME [88-89] as well as by private industry [90], the basic MEP paradigm incorporates the following key structural elements:

- a formal orientation course for new freshmen;
- clustering of underrepresented students in common sections of their classes;
- a student study center; and
- structured study groups.

More recently, other structural elements, such as student and faculty surveys and other assessment tools [72, 91–92], rigorous peer and professional advising efforts [93–94], undergraduate research programs [95], and even computer-aided learning [96–97] have been added to the basic MEP paradigm with varying degrees of success.

Another decade-old approach to academic intervention sharing much in common with the MEP model is the National Science Foundation's Louis Stokes Alliances for Minority Participation (LSAMP) program [98]. The LSAMP program encourages minority students to complete baccalaureate degrees not just in engineering, but in all STEM fields. Currently, approximately 20,000 LSAMP participants receive baccalaureate degrees in STEM fields each year. Rather than support individuals or single institutions, LSAMP creates partnerships among academic institutions (minority and majority), government agencies and laboratories, industry, and professional organizations. LSAMP activities help minority students fulfill their potential in college and sustain their interest in STEM fields and graduate study through hands-on research experiences. A residential summer bridge program enrolls graduating high school seniors in college preparatory courses and, in addition, teaches them study skills and time management [99]. LSAMP also provides mentors and role models and supports drop-in centers on college campuses for program participants. With the legal sanction of targeted student programs lifted from federal agencies [49], institutional programs such as LSAMP supporting colleges and universities that enroll significant numbers of underrepresented minorities have become an essential policy tool. Accountability for retention and graduation rests at the institutional level, not with individual departments or other units.

It is important to point out that an essential component of the effectiveness of any MEP-type program is that it remain focused on academics, as opposed to taking an approach which is oriented towards "student services" (i.e., outreach, admissions, advising, counseling) [76]. Broadly interpreted, student services could include these traditional activities as well as other types of services such as helping students obtain scholarships, helping to place them in engineering-related summer jobs, and overseeing student organizations. Intervention programs whose primary focus is to deliver services to students tend to have little or no impact on student academic performance. On the other hand, academic focused programs which include the basic aspects of the MEP model can be extremely effective. For example, in 1985, the California Postsecondary Education Commission evaluated twelve MEPs and found that students participating in these programs were being retained at higher rates than all engineering students at each of the twelve institutions, and at three times the rate of minority students not participating in the programs. Equally impressive were statistics from the program at UC-Berkeley, where participating students earned on average one letter grade higher in their mathematics and science courses than non-participating minority students, and exceeded the average grades achieved by white students in the same courses [100]. Similar results have been achieved by the Office of Minority Educational Development (OMED) at the Georgia Institute of Technology, an MEP-like program which produces minority students who perform academically at or above the level of majority students [53, 84].

Central to creating the effective educational environment inherent by these programs is the concept of *collaborative learning*. When institutions promote a high level of collaborative learning among a group of students, positive outcomes including improved academic performance, improved retention, enhanced student satisfaction with the learning experience, improved oral communication skills, and higher student self-esteem are achieved [76]. The following sections explore the basic building blocks of a successful collaborative learning environment in more detail.

2) Freshman Orientation: To ensure that minority students know each other and and are taught the benefits of groups study early on during their matriculation (which are necessary conditions for collaborative learning to occur), an orientation course for its minority freshmen should exist [101–104]. Ideally the course should span the entire academic year and award academic credit.

The primary goal of this course is to build the freshman students into a supportive group. In addition to knowing each other, the freshmen develop a sense of group cohesiveness and group spirit. Within the course, encouraging students to engage in collaborative learning should be a strong priority. Many minority students developed a pattern in high school of doing all their studying alone and separating their academic life from their social life. They may have found their high school work to be less challenging, and thus had no need to study with other students. This pattern of behavior, however, does not lend itself to success in engineering study except for the very brightest.

3) Clustering: For students to engage in meaningful group study, they must be enrolled in the same courses, and they must be in the same sections of those courses. By clustering minority engineering students, these two conditions required for collaborative learning are met. Clustering brings students into a supportive environment where they can develop their confidence, strengthen their study skills, learn the value of collaborative study [105–106]. Clustering also has the additional benefit of reducing ethnic isolation. Implementation of clustering is extremely simple. It only requires: 1) identifying the cluster sections; 2) advising students to register for those sections; and 3) ensuring that the students can enroll in them. (Note that clustering does not imply establishing "minority-only" sections).

4) Study Center: The student study center is the physical location that becomes the focal point for an effective minority engineering program. It provides students with a place to study, individually or in groups, and is a convenient location for any tutoring services. The study center's foremost benefit is that it promotes collaborative learning. It serves as a home base for the students, a place where they can leave personal belongings, meet with fellow students, plan activities, or just find support. The study center thus has the additional benefit of sending minority students signals that they are accepted, that they belong. Finally, the study center promotes communications within the minority engineering program, enabling program staff to transmit messages to students and students to contact one another.

5) Structured Study Groups: The previous sections have described three structural elements—a freshman orientation course, clustering, and a student study center—which promote collaborative learning. All three require students to take the primary initiative in developing study partners or study groups. A desirable adjunct to these elements, therefore, are structured study groups [107]. One of the more effective model for structured study groups is the mathematics/science workshop model developed by Uri Treisman for the Professional Development Program (PDP) at UC-Berkeley [100, 105]. These workshops were structured group study sessions. Workshop participants (i.e., students clustered in common sections of a course) met as a group with a workshop leader for two or three two-hour sessions each week. The students were required to have attempted the assigned homework prior to the workshop. At the workshop, the students worked in small groups on sets of problems prepared by the workshop leader in consultation with the course instructor. The workshop leader assists students as problems arise and may give a short lecture if several groups are encountering common problems. Since their inception at UC-Berkeley, PDP workshops have been replicated at a large number of both undergraduate teaching institutions and research institutions, and for a wide range of courses [79]. Workshop leaders have been faculty, graduate students, and sometimes even undergraduate students.

E. Graduate Study

Although the focus of this paper is on undergraduate success in engineering, it is clear that such success is a necessary precursor for admission and success in graduate engineering programs. Therefore, graduate admission and enrollment can be considered as an indicator of undergraduate success.

One of the most effective approaches for motivating students to pursue advanced degrees and research careers in science and engineering is a fruitful research experience as an undergraduate. Such experiences can help students who exhibit uncertainty or a lack of confidence regarding attending graduate school. Many minority students fit into these categories. While some are unsure whether to pursue graduate education at all, others want an advanced degree, but are uncertain about the other variables involved in this decision (i.e., what school to attend, MS versus MBA, etc.). Ultimately, the decision of the minority student to attend graduate school is profoundly affected by the amount of faculty involvement in their undergraduate career [108]. Quality interactions with engineering faculty can have a significant impact on a student's decision to pursue graduate education, since such interaction provides the student with effective role models.

Undergraduate research programs [109–111] are an important component of enhancing minority enrollment in advanced degree programs and ultimately, increasing the size of the minority Ph.D. population. A study of graduate engineering education of underrepresented populations by Reichert and Absher measured the persistence of various population segments in proceeding from undergraduate to graduate programs [112]. Results indicate a persistence gap between majority students and underrepresented minorities only when proceeding from the Bachelor's to the Master's degree. The absence of such a gap when proceeding from either the B.S. or M.S. to the Ph.D. implies that once admitted to graduate school, underrepresented students are equally committed to pursuing the doctorate.

V. Conclusion

This paper has provided a description of the various factors that contribute to the success of minority students in engineering programs. Success was related to pre-college preparation, recruitment programs, admissions policies, financial assistance, academic intervention programs, and graduate school preparation. Each of these sub-topics was investigated and correlated to the engineering success of underrepresented students. The salient points resulting from this investigation are as follows:

- The national K-12 educational system, to a large degree, has failed to adequately prepare minority students in science, mathematics, engineering, or technology.
- The performance gap between underrepresented and white and Asian pre-college students can generally be attributed to disparities in resources, including funding, availability of qualified teachers, high-quality curricula, and computer/Internet access.
- Targeted strategies such as student enrichment and intervention programs, promotion of engineering preparation, teacher effectiveness programs, and systemic educational reform initiatives have the potential to increase the number of underrepresented pre-college students progressing in college STEM programs. These strategies should be systematically evaluated. Based on such an evaluation, the most effective strategies should be institutionalized and mainstreamed so that all students can benefit from them.
- The stereotypical image of scientists and engineers portrayed in the media hinders the recruitment of minority students into engineering fields.
- Challenges to affirmative action policies in higher education admissions have contributed to lower enrollment rates for underrepresented students in STEM fields. However, some institutions have demonstrated successful outcomes in the absence of such policies.
- The NACME *Vanguard* program has contradicted the efficacy of standardized testing as a measure of student potential and introduced techniques that allow students from non-traditional educational experiences to excel in the engineering environment.
- The availability of financial aid is crucial to increasing the enrollment and success of these students in engineering curricula. It is important that aid consist of scholarships and grants, as opposed to loans.
- By raising the national retention rate to 80 percent, parity in undergraduate engineering enrollment could be achieved within six years at the cost of approximately $370M.
- Even after a quarter-century, the Minority Engineering Program (MEP) paradigm remains a compelling example of a model that has demonstrated the capability to facilitate student success. This model includes a formal orientation course for new freshmen, clustering underrepresented students in common sections of their classes, a student study center, and structured study groups.
- It is clear that success in undergraduate study is a necessary precursor for admission and success in graduate engineering programs.

This paper has also described possible research opportunities for explaining factors that contribute to engineering success of minority students. Several exisitng programs and activities—including numerous pre-college engineering preparation programs, *Vanguard*, various financial assistance efforts, and the ubiquitous MEP model, to name a few—suggest that *the problem of minority underrepresentation and success in engineering is soluble.* What have been lacking are the resources and collective national will to propogate these efforts and continue to learn from them. That is perhaps the premier challenge to engineering education for the first decade in the 21st century.

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AUTHOR BIOGRAPHIES

Dr. Gary S. May is the Executive Assistant to the President and Motorola Foundation Professor of Electrical and Computer Engineering at the Georgia Institute of Technology. In this capacity, Dr. May acts as the president's chief liaison, serving as a link to that office and providing feedback from numerous constituencies on and off campus. He received the Bachelor's degree in Electrical Engineering from the Georgia Institute of Technology in 1985, and the M.S. and Ph.D. degrees in Electrical Engineering and Computer Science from the University of California Berkley in 1988 and 1991, respectively. Dr. May was a National Science Foundation (NSF) National Young Investigator (1993–98), Georgia Tech's Outstanding Young Alumnus (1993), received Georgia Tech's Outstanding Service Award (1999), and was named a Giant of Science by the Quality Education for Minorities network (2001). He was a member of the NSF Engineering Advisory Committee (1994–2000), served on and chaired the NSF Committee for Equal Opportunity in Science and Engineering (1997–2001), and was Editor-In-Chief for *IEEE Transactions of Semiconductor Manufacturing* (1997–2001). Dr. May currently serves as chair of the National Advisory Board for the National Society of Black Engineers.

Address: Office of the President, Georgia Institute of Technology, Atlanta, GA, 30332-0325, telephone: 404-894-5053, fax: 404-385-2994, e-mail: gary.may@carnegie.gatech.edu.

Dr. Daryl E. Chubin is Senior Vice President, Policy and Research, at the National Action Council for Minorities in Engineering (NACME), Inc., in New York City. He was appointed March 2001, after fourteen-and-a-half years in federal service, the last three as Senior Policy Officer for the National Science Board at the National Science Foundation (NSF). Chubin is a Fellow of the American Association for the Advancement of Science (AAAS), Past Chair of the AAAS section on Societal Impacts of Science and Engineering, Past President of the Commission on Professionals in Science and Technology, Co-chair of the 2002 Gordon Research Conference on Science and Technology Policy, a member of the National Academy of Engineering Committee on Diversity in the Engineering Workforce, and an Integrator for BEST (Building Engineering and Science Talent), a public-private partnership created to implement the recommendations of the Morella Commission.

Address: NACME, Inc., Empire State Building—Suite 2212, 350 Fifth Avenue, New York, NY, 10118-2299, telephone: 212-279-2626, x218, fax: 212-629-5178, e-mail: dchubin@nacme.org.