Engineering in the K-12 Classroom
An Analysis of Current Practices & Guidelines for the Future

A Production of the ASEE EngineeringK12 Center

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Executive Summary

America's progress has been synonymous with innovation. Thorough grounding in science and mathematics contributes to people's full participation in the professional, civic, and intellectual possibilities available in American society. Corporate growth and economic development, coupled with a higher standard of living, are inextricably tied to technological advancement. To continue to grow, however, the United States needs a technically literate society and an engineering-minded workforce. Unfortunately, these are two key areas in which our education system often fails to meet the mark. The good news is that a solution can be found in our K-12 classrooms.

Evidence indicates that the need for technically savvy workers is not being met. In recent years, companies have annually spent almost $60 billion on training, much of which paid for workers' training in basic skills that should have been taught in school.[1] Meanwhile, the United States' poor performance in teaching math and science eliminates many of the best and brightest schoolchildren from the ranks of future scientists and engineers. With little chance to learn in school how science and math skills might translate into professionally useful knowledge, students are unable to make informed choices about further education and work options. As a result, many students who do undertake science and engineering studies in college are unprepared and drop out in frustration; other, potentially capable students never consider these subjects in the first place. In both cases, precious human and institutional resources are squandered. Further, females and underrepresented minorities are under-represented in both our college-level engineering programs and in the national engineering workforce. Enhanced engineering education in our K-12 classrooms can provide more students a more specific understanding at an earlier age of what a technical career entails.

The American Society for Engineering Education has embarked on an ambitious effort to promote and improve K-12 engineering education. To start, ASEE created a guidebook to engineering education for high schools students, called *Engineering, Go for It!*, and an e-newsletter called *Go Engineering!* for teachers, guidance counselors, and outreach program leaders. These publications address everything from the opportunities and rewards of studying and working in technology fields to news items, policy developments, and innovative program activities related to K-12 engineering education. Almost 350,000 high school students have received the guidebook and the newsletter reaches 10,000 K-12 educators every month. Further, ASEE has surveyed outreach program leaders to understand current outreach practices, as well as K-12 teachers from all grades to comprehend teachers' attitudes on K-12 engineering education. ASEE also brought together leaders from industry and higher education, along with K-12 teachers, for a Leadership Workshop on K-12 Engineering Outreach, held just before the 2004 Annual Conference and Exposition in Salt Lake City, Utah. This paper draws on all that

[1] *Training Magazine*. "Industry Report 2001." Minneapolis: Bil Communications. http://www.trainingmag.com/training/images/pdf/2001_industry_report.pdf

we at ASEE have learned from these efforts. And it also lays out some guidelines for how K-12 engineering education works best and defines key challenges confronting the field.

The paper will first examine why there is cause for concern, incorporating statistics demonstrating that the United States must improve the technical literacy of its population, and especially its workforce, to maintain global leadership in economic growth, military capability, and the capacity for technological innovation. These improvements should focus sharply on females and underrepresented minorities, who participate in engineering at rates far below their share of the overall workforce. The paper then examines K-12 teachers' attitudes on engineering education, using statistics from a recent ASEE survey. Current practices are then discussed, drawing from the survey of outreach programs. Finally, a set of guidelines for future work in the field, mostly gleaned from discussions at the K-12 Leadership workshop, are examined.

Many groups with a stake in K-12 science, technology, engineering, and mathematics (STEM) education make a strong case about the need for improved technical literacy, especially for females and minorities. However, repeatedly making the case to each other is simply "preaching to the choir." The larger issue, then, is the upshot—where do we go from here? What can K-12 engineering educators do to advance the state of the field? Experts from all levels—K-12 teachers, university professors, industry and government representatives—offered answers to these questions at the ASEE K-12 Leadership Workshop. Coupled with the information from the surveys, the ideas and suggestions form a set of six guidelines for improving K-12 engineering education and outreach:

- *Hands-on learning*: Make K-12 science curriculum less theory-based and more context-based (hands-on), emphasizing the social good of engineering and demonstrating how it is relevant to the real world
- *Interdisciplinary approach*: Add a technological component to all subjects and lessons, and implement writing guidelines in math and science courses
- *Standards*: Involve engineering in K-12 lessons that map to state standards for math and science. Further, states should follow Massachusetts and enact state standards for engineering
- *Use/Improve K-12 Teachers*: Engage more K-12 teachers in outreach efforts and curriculum writing, and increase teacher salaries to attract the best technological minds to teaching
- *Make Engineers "Cool"*: Outreach to urban schools and females more aggressively, and create more mentors and role models to attract these constituencies
- *Partnerships*: Create better incentives for all groups to engage in K-12 outreach (especially higher education and industry)

While an exhaustive list of recommendations to promote and enhance engineering education in the K-12 world is virtually impossible, these six guidelines hit the high points mentioned by experts at the K-12 Leadership Workshop. Moreover, they answer the call of the majority of teachers surveyed, who face formidable constraints even while believing that engineering is important in their classrooms. These guidelines, then, emerge from current outreach efforts and seek to move them a step further, offering a broader base for improving the quality, methodology, and reach of K-12 engineering education.

I. Introduction

A vibrant engineering education enterprise benefits civic, economic, and intellectual activity in the United States. Engineering graduates learn to integrate scientific and engineering principles to develop products and processes that contribute to economic growth, advances in medical care, enhanced national security systems, ecologically sound resource management, and more. As a result, students with engineering degrees bring highly prized skills into a wide spectrum of sectors in the American workforce.

Further, building a capacity to add intellectual value to existing technological systems has become a core strategy for corporate growth. Inventions and enhancements in technology enable greater productivity and profitability. A vast array of benefits flows from this cycle of technology-driven business success, including rising standards of living, new kinds of career options, and strengthened national security in both economic and military arenas. Engineers create, manage, and maintain the processes and products of innovation. Expanding the reach of engineering education into the K-12 world promises to swell the number of students graduating into the workforce with the skills and interests needed to keep the innovation economy growing.

Clearly, there is a societal argument for the need for engineering education in our K-12 classrooms, as technical literacy promotes economic advancement. There is also a statistical argument, as the number of students entering engineering schools declines, relative to overall enrollments, and the number of women and underrepresented minorities in engineering remains well below the national average for higher education.

A survey of current teachers provides another stark reminder of the need to make engineering a useful resource for K-12 STEM education. While most teachers believe incorporating engineering concepts into their classrooms is important, they also believe engineering is inaccessible to their female and minority students as compared to other career paths.

Experts in the field—from K-12 teachers to university professors to industry and government representatives—have also called for increased engineering exposure in the K-12 world. At the ASEE Leadership Workshop on K-12 Engineering Outreach, held just before the 2004 ASEE Annual Conference and Exposition in Salt Lake City, Utah, K-12 experts spoke of the need to make engineers “cool,” map engineering to state standards, and teach the social good of engineering—among other innovative ideas that will help attract more students to the field.

What are we currently doing to tackle the problem? A survey of outreach programs demonstrates that current practices are reaching many students, extolling the importance of engineering concepts. However, the survey also demonstrates that as a society, there is tremendous room for growth in this area.

So how do we accomplish this goal? How do we ensure that the United States remains the most technologically advanced, most economically dynamic country in the world? How can we attract more students—and in particular females and minorities—to engineering schools and engineering careers? This paper will set out to define a set of guidelines for doing just that.

II. Why Are We Concerned?

“No one should have to wait until after high school to be exposed to engineering. Early exposure to engineering will help high school students make better decisions on course selection. How many high school students do not know enough to even consider engineering as a career path, and how much of a loss is that?”

> *-John Brighton, Assistant Director for Engineering, National Science Foundation, Keynote Address at ASEE’s Leadership Workshop on K-12 Engineering Outreach*[2]

The main constituencies concerned with K-12 engineering education have typically been K-12 teachers, colleges and universities, and industry. Each group has differing motivations for advancing engineering in the K-12 world. Even though less than one percent of K-12 instructors actually teach courses on engineering and technology, K-12 teachers still want to better prepare their students for living and working in an advanced technological society.[3] Engineering colleges worry about K-12 engineering education mostly because they need to recruit and retain their students. Indeed, the number of engineering degrees awarded has declined sharply in the past twenty years, leveling off only recently, and many students who do enter engineering programs leave after the first year for other disciplines. And corporations have a vital interest in ensuring their workforce is sufficiently skilled to innovate, create, and advance the company’s products and goals.[4] While offshoring has become a major political issue, one company representative at the Leadership Workshop noted that his company has only

[2] See Appendix A for the workshop program
[3] National Science Foundation, 2002. This statistic was incorporated in John Brighton’s PowerPoint presentation, delivered at the 2004 ASEE Leadership Workshop on K-12 Engineering Outreach, Salt Lake City, Utah.
[4] These ideas are culled from discussions during the 2004 ASEE Leadership Workshop on K-12 Engineering Outreach, Salt Lake City, Utah.

looked to other countries such as India and China for workers because they do not believe they can find the talent in the U.S. Regardless of the goal, therefore, all groups—and society as a whole—have a stake in promoting engineering to our future students and workforce. K-12 engineering education can be an answer.

One of the stiffest challenges facing engineering education is attracting students to the field from the entire spectrum of American society. Female students make up 20% of engineering undergraduates, but 55% of all undergraduates; African-Americans, 5.3% in engineering, 10.8% overall; and Latinos, 5.4%, compared to 6.4% overall (See Charts 1-4).[5] Worse, the percentages in engineering have been decreasing in recent years, while overall participation in higher education among these groups has increased considerably.

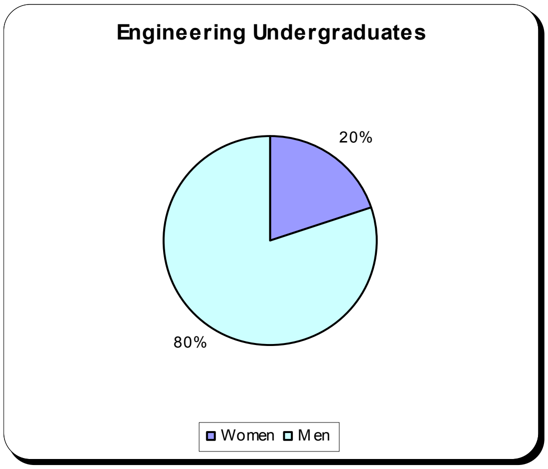


Chart 1

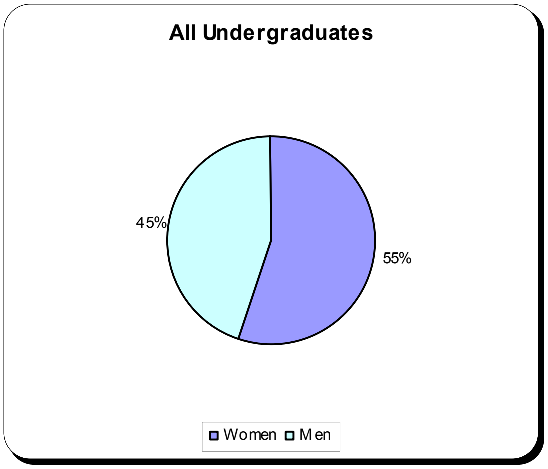


Chart 2

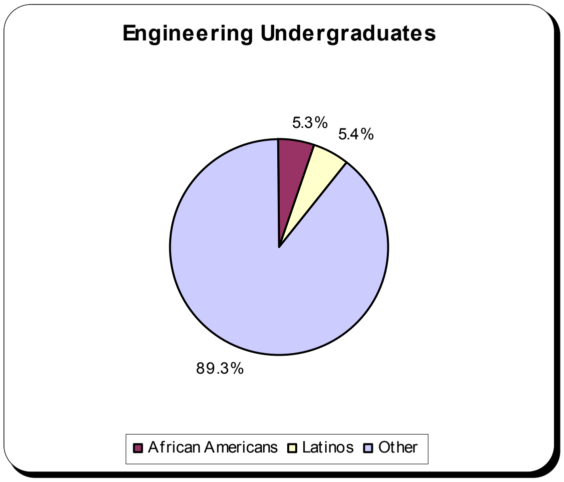


Chart 3

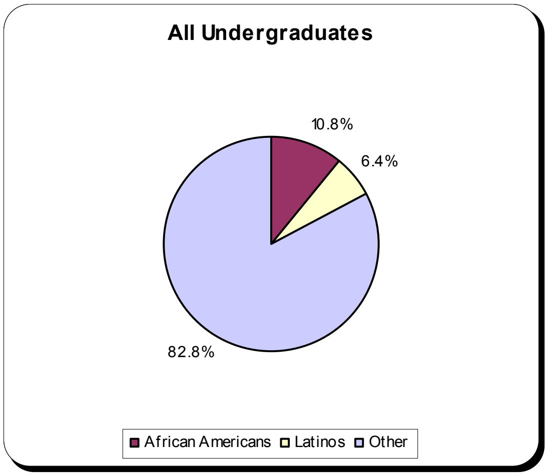


Chart 4

In the workforce, the story is the same. According to the National Science Foundation, women comprise 46% of the total workforce but hold only 24% of jobs in technical fields. African-Americans and Latinos register at 13% each of the total

[5] *Profiles of Engineering and Engineering Technology Colleges*, ASEE, 2004.

workforce and only 3% of the technical workforce (See Charts 5-8).[6] At a time when these groups continue to increase their share of the total workforce, these numbers are especially worrisome. Engineering and technology are losing the battle for the hearts and minds of the fastest-growing sectors of tomorrow's workforce.

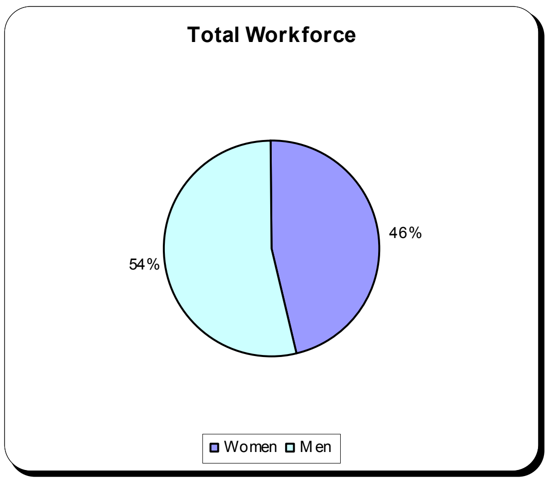
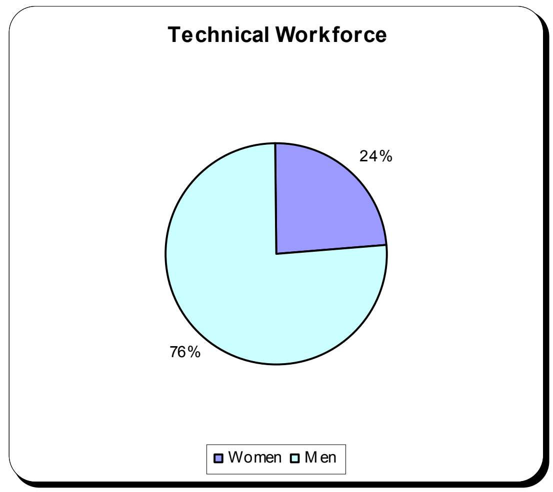


Chart 5



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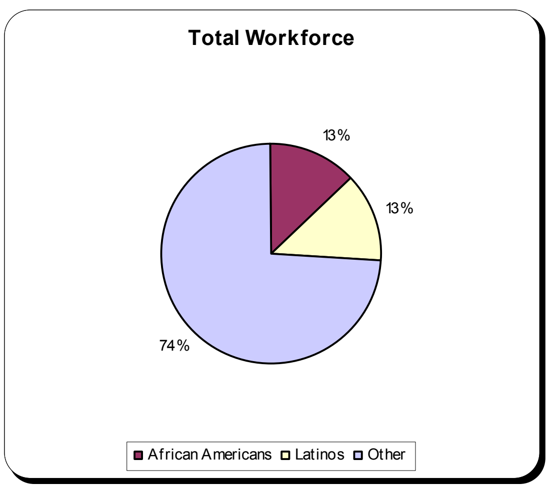

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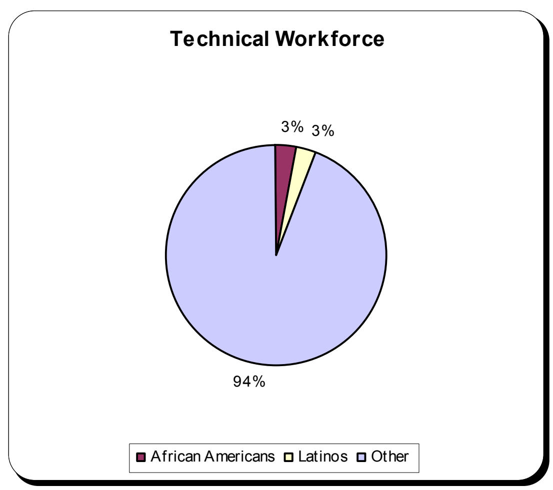


Chart 8

III. Attitudes of K-12 Teachers

"My attitude about engineering is VERY positive. One of the few regrets I have about my career choice is that I hadn't a clue about engineering when I was growing up in Hawaii in the 50's."

[6] *The Science and Engineering Workforce: Realizing America's Potential*, National Science Board, August 2003.

-Teacher who completed ASEE's Teacher Attitudes Survey

As part of the efforts to compile a list of guidelines for K-12 engineering education outreach, ASEE surveyed current K-12 teachers to determine their attitudes toward engineering and other subjects in their classrooms.[7] Specifically, the survey sought to understand what teachers think of engineering as an academic and career pathway for their students.

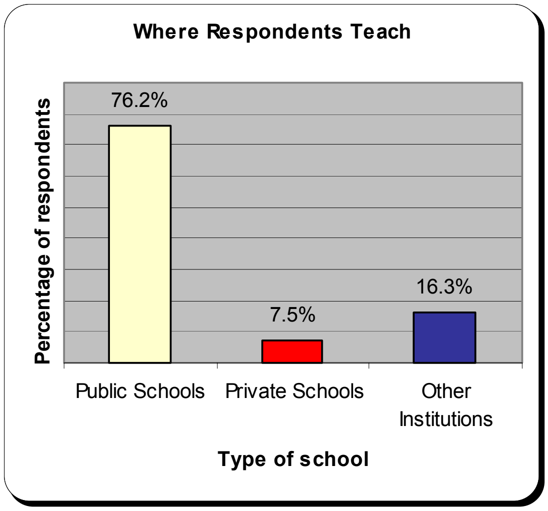
There were 522 total responses to the online survey, which took teachers approximately ten minutes to complete.[8] There was even gender representation, as 50.6% of respondents were female and 49.6% were male. There was a wide range of ages represented: 7.7% were between the ages of 20-29; 19.3% were between the ages of 30-39; 33.9% were between the ages of 40-49; 32.4% were between the ages of 50-59; 5.7% were between the ages of 60-69, and 0.9% were 70 or older. However, the sample was not ethnically diverse, which is a potential weakness regarding validity of the results: 92.3% of the respondents were white; 2.9% were Hispanic; 1.9% were African-American; 1.4% were Asian American; 0.9% were "other ethnicity;" and 0.2% were Native American.

An overwhelming majority of respondents—76.2%—teach at public schools, while 7.5% of respondents teach at private schools. This is fairly representative of the school population, as 11% of the nation's elementary and high school students are projected to attend private schools in 2004.[9] The final 16.3% of respondents teach at "other" institutions, such as at vocational schools, in professional development, at a university or museum, or at another type of educational institution. Therefore, the results provide a representative glimpse into the attitudes of many different types of educators (See Graph 1).

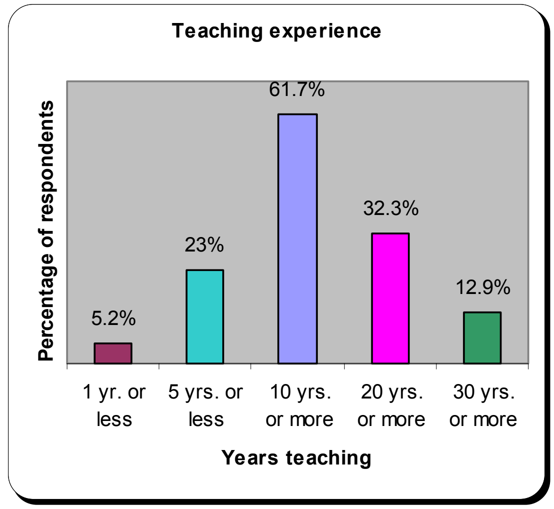
[7] To see the survey, visit: http://www.engineeringk12.org/teachers/survey1.cfm.

[8] No advanced statistical analysis was used in this examination. However, a summary of the survey results still provides a clear picture of teachers' attitudes. To see the complete survey results, visit: http://www.engineeringk12.org/teachers/survey1Results.cfm.

[9] *Back to School*. U.S. Census Bureau. July 6, 2004. See: http://www.census.gov/Press-Release/www/releases/archives/facts_for_features_special_editions/002263.html.



Graph 1



Graph 2

Our respondents also had a wide range of teaching experience. While only 5.2% have been teaching for one year or less and 23.0% have been teaching for five years or less, 61.7% have been teaching for ten or more years, 32.3% have been teaching for 20 or more years, and 12.9% have been teaching for 30 or more years (See Graph 2). Further, virtually all of the respondents teach science, math, or technology-related subjects. Over half of the educators teach in high schools, but there is substantial elementary and middle school representation as well.

Clearly, then, the survey results will reflect the attitudes of some very experienced educators teaching science, math, and technology courses to all age groups and in public, private, and "non-traditional" settings. The only potential weakness in the sample is the ethnic representation. With this context in mind, what do the teachers have to say? In general, they have a positive outlook on engineering education, and they believe it important to implement engineering concepts in the classroom. However, they also view engineering as "inaccessible" to some of their students compared to other careers.

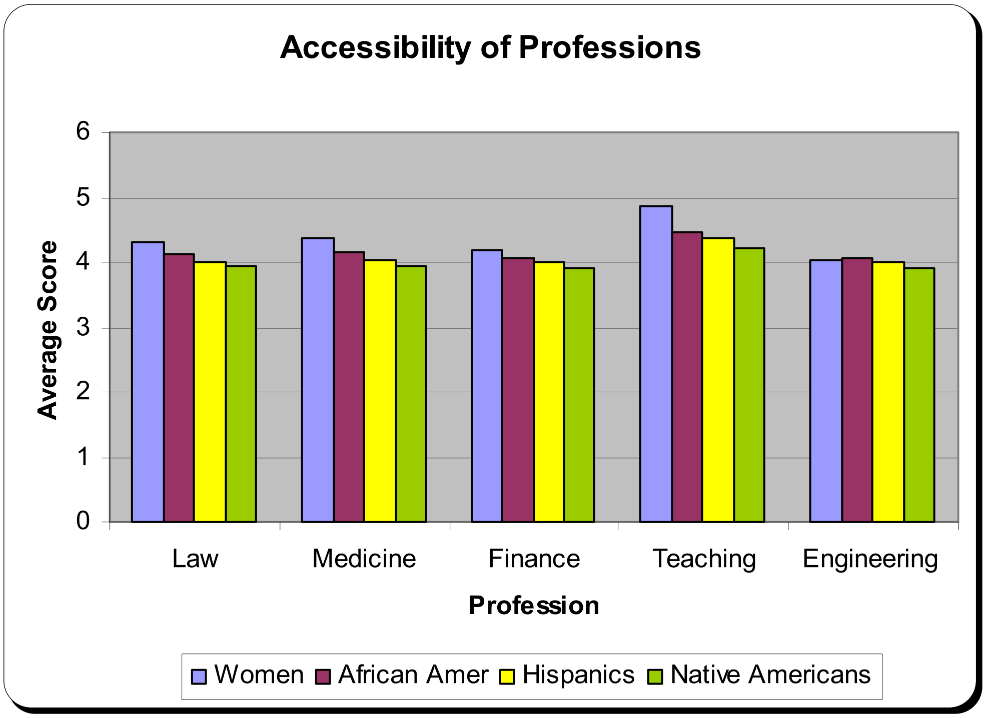
Overall, K-12 teachers have a positive attitude toward engineering. 66.9% of respondents strongly agreed and 28.2% agreed with the statement, "Engineering has a large impact on my daily life," while 66.4% strongly agreed and 30.8% agreed with the statement, "Engineering has a large impact on the well-being of the country." The teachers also believe that exposure to engineering concepts is a crucial component of a well-rounded education. 37.7% strongly agreed and 51.5% agreed with the statement, "A basic understanding of engineering is important for understanding the world around us." Teachers see the benefit of engineering curriculum in teaching other subjects as well. 16.2% of teachers strongly agreed and 61.2% of teachers agreed with the statement, "Engineering can be a way to help teach students about business," while 25.0% strongly agreed and 50.9% agreed with the statement, "Engineering can be a way to help teach students history."

Teachers also understand the intellectual challenge and social rewards of an engineering career. 32.3% strongly disagreed and 44.8% disagreed with the sentiment, "Engineers do boring things," and 14.8% strongly agreed and 49.7% agreed with the statement, "Engineers are fun people." Additionally, when asked whether, "Engineers love their work," 15.8% strongly agreed and 54.8% agreed. 35.9% strongly agreed and 56.8% agreed with the statement, "Engineers make people's lives better." Finally, only 0.5% strongly disagreed and 8.9% disagreed with the statement, "Engineers make a lot of money." 40.5% of respondents were neutral on this question, while 46.0% agreed.

The results show that teachers believe engineering is a noble profession with tangible and intangible rewards, and that an engineering education can provide many benefits to students. When asked about the accessibility of an engineering education and career, however, the story was different.

The teachers were asked, "How many of your students could succeed as engineers?" Only 2.9% responded "all," 27.9% said "most," 56.3% said "some," and 12.8% said "few." That is, even teachers believe that engineering is not open to a large number of their students.

The picture became even starker when the survey delved deeper into which types of students were unable to become engineers. Respondents were asked how accessible certain professions were to various groups of students, on a scale of 1 to 5 with 1 being "very inaccessible" and 5 being "very accessible." In general, the scores were high for all professions, but comparatively, the scores were lower for engineering. When asked how accessible the professions of law, medicine, engineering, finance, and teaching were for women, engineering had the lowest average score—4.85 for teaching, 4.38 for medicine, 4.30 for law, 4.17 for finance, and 4.02 for engineering. The story was much the same for African-Americans, with the accessibility of teaching as a profession way above the others and engineering near the bottom (the average score for teaching was 4.46, while the average score for engineering was 4.06). Accessibility scores for Hispanics were a little different—this time, engineering ranked just as low as law, medicine, and finance, at 4.00. However, the accessibility of a teaching career for Hispanics ranked much higher, with an average score of 4.36. Accessibility scores for Native Americans were approximately on par with the scores for Hispanics—teaching came out on top at 4.22, while the other professions, including engineering, were well behind at 3.92 (See Graph 3).



Graph 3

Further, teachers believe that majoring in engineering in college is harder than majoring in many other subjects. 32.5% strongly agreed and 30.9% agreed that majoring in engineering is harder than majoring in English, while 26.0% strongly agreed and 29.8% agreed that engineering is harder than finance, 35.5% strongly agreed and 31.4% agreed that engineering is harder than sociology, and 13.0% strongly agreed and 25.7% agreed that engineering is harder than biology (42.0% were neutral on this question). Therefore, while teachers believe that an engineering education can provide a myriad of social and intellectual rewards, they also think that engineering is harder than many other subjects—a feeling they likely pass on to their students, and especially the ones less likely to have the doors of engineering open to them.

Finally, most of the teachers surveyed said that they and their students would benefit from increased engineering exposure in their classrooms. 39.1% strongly agreed and 51.2% agreed with the statement, "Understanding more about engineering can help me become a better teacher," and 28.2% strongly agreed and 55.8% agreed that their students would be interested in learning engineering (See Charts 5 and 6).

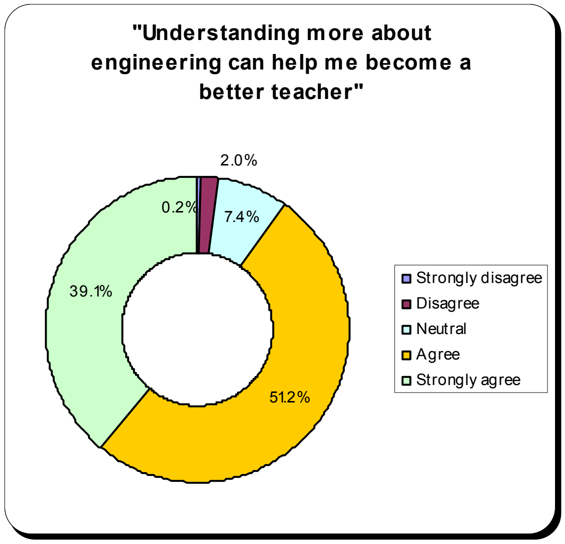


Chart 5

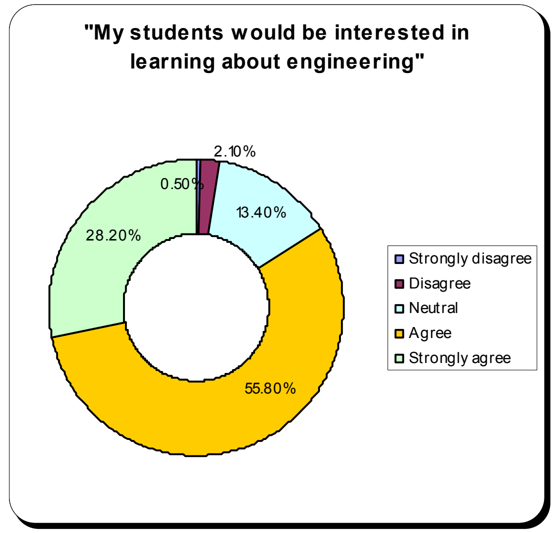


Chart 6

Clearly, the teachers' attitudes provide the K-12 engineering education community with an interesting paradox. Teachers are overwhelmingly positive about engineering in the abstract, extolling the virtues of an engineering education and career. However, when it comes down to their students, they believe that many—and especially females and minorities—cannot succeed in the engineering world. This is true even of a sample comprised mostly of white teachers, who believe other professions open their doors more to minorities than engineering does. Our set of guidelines for K-12 engineering education will need to address this inaccessibility issue.

IV. What Did the "Experts" Say at the Leadership Workshop on K-12 Engineering Outreach?

"We teach teamwork but we don't test teamwork."
-Teacher at the Leadership Workshop on K-12 Engineering Outreach

ASEE hosted a Leadership Workshop on K-12 Engineering Outreach in Salt Lake City, Utah, on Saturday, June 19, 2004, just before the 2004 ASEE Annual Conference & Exposition. Over 150 educators, including K-12 teachers, university professors, and industry and government representatives attended the day-long workshop to discuss K-12 engineering outreach. There was a large contingent of teachers from Project Lead the Way, a high school engineering curriculum program, as well as K-12 teachers from around the country, university officials conducting outreach programs on their campuses, and representatives from companies such as HP, Autodesk, Ford, PTC Software, and Microsoft. The goal was to bring experts in K-12 engineering education from various groups together to discuss and debate incentives, issues, and barriers in the field.

The morning session was filled with speeches and panel discussions. Dr. John Brighton, Assistant Director for Engineering at the National Science Foundation, gave the keynote speech. Afterwards, there was a panel of higher education and industry representatives, and another with K-12 teachers. The audience was encouraged to actively participate, and they did so by asking engaging questions of the panelists and each other. The afternoon was devoted to break-out sessions, where attendees were able to discuss issues such as partnerships, policy goals, and resources, among others. The morning panels provided the foundation for the breakout session discussions, which have provided the backbone for this paper's list of guidelines.

Several main issues came up during the panel discussions and breakout sessions. One interesting point was that while all of the groups involved are concerned about K-12 engineering education, the groups have differing reasons for their concern. K-12 teachers are interested in graduating smarter and well-rounded students; university professors consider how their efforts will help them recruit and retain more students; and industry representatives want a diverse workforce that is technologically savvy. In the same vein, all of the groups face constraints in promoting engineering education: K-12 teachers must deal with state standards and assessment; higher education professors are concerned with promotion and tenure; and industry must be able to produce easily definable and measurable outcomes in order to justify investing their money and resources in the cause. If nothing else, the Leadership Workshop allowed these various groups to understand each other's incentives and barriers to promoting engineering education in our classrooms.

The Workshop also allowed participants to vigorously discuss what works for them in engineering outreach. Many of the teachers gave anecdotal evidence that hands-on learning is the best method for attracting more students to engineering. They described the interactive experiments and lessons they utilize to make engineering come alive for their students. The sense was that engineering education needs to become less theory-based and more context-based, to demonstrate engineering's relevancy in the "real world."

Many of the educators said that while they believe engineering is important in their classroom, they do not have the time or resources to implement engineering lessons. That led to a discussion of a more "interdisciplinary approach," whereby a technological spin is added to subjects such as writing and history, and writing instruction is added to science and math classes. In this way, the teachers can add engineering content without drastically altering their lesson plans. Further, an interdisciplinary approach can help the lessons become hands-on and make engineering fun for students.

The issue of state standards and assessment produced another lively discussion. In fact, standards seemed to be a major obstacle facing many of the educators, with some teachers saying that standards inhibit creativity and encourage compartmentalization. Teachers are tested on certain subjects, so they center their lessons around these areas.

As one teacher succinctly put it, “It’s only about the test.” In Massachusetts, engineering is now part of the state standards after intense lobbying from teachers and universities. The K-12 teachers commented that if their states tested for engineering, they would have more time, resources, and institutional buy-in to implement engineering lessons. The consensus of the group was that teachers should map their math and science lessons to the state standards, while trying to lace these lessons with hands-on engineering ideas. On a policy level, the workshop participants called for other states to follow Massachusetts and adopt engineering standards.

All groups also said that additional effort is needed to improve the quality of K-12 teachers. They encouraged outreach programs to recruit more teachers, and called on school districts to engage more teachers in writing curriculum. Teacher preparation is key, participants said, as is professional development or the re-training of current teachers. Further, teacher certification courses need to be “user friendly,” by offering distance learning or evening classes and collaborating between universities and industry for training ideas, for example. Some participants called for a national model to certify K-12 teachers. Others said that there needs to be a push within the K-12 community to understand what engineering really is and how it can be easily implemented in the classroom. Additionally, participants explained the need for additional outreach to “forgotten” groups that are important to the K-12 world, such as parents, school counselors, college advisors, and working engineers. Indeed, practicing engineers should be encouraged to enter the K-12 classroom to teach. Finally, many Workshop participants felt that teacher salaries should be increased and be made market- and merit-based to encourage educators to become better qualified and stay in the profession. The sense was that a lot more can be done to use and improve teachers and other K-12 influencers.

Along the same lines, participants noted that role models are the key to making engineering “cool.” There is a need to reach out more aggressively to urban schools and female groups, and to create more mentors and role models. Educators need to understand the current pedagogy and its implications on women and minorities. They must also recognize when stereotypes about engineering begin and combat these stereotypes among younger students, teaching them the virtues of engineering and technology. Society must view “nerds” as loveable and likeable, which will take away the social stigma of choosing engineering as a career path. The influence of a student’s peers cannot be overlooked, and engineering college students can also be utilized more effectively in the K-12 classroom. “We need to make engineering sexy,” one participant exclaimed.

Additionally, engineering education should focus on teaching the social good of engineering. Studies have shown that girls are discouraged from engineering because of societal norms, and because they do not see how an engineering career can help society. “Most girls—and minority students—want to know how what they’re learning can be applied in real life,” said Pat McNees, who has studied ways to attract females to science and engineering careers. "Engineering takes on meaning when students have to navigate a campus in a wheelchair (or wearing spectacles smeared with Vaseline, to get a sense of navigating nearly blind) before being asked to design handicapped-accessible facilities."[10]

Another line of discussion centered around partnerships among K-12 schools, universities, industry, and government. The main question is how the K-12 community can convince constituencies to work together, agree on outcomes, and optimize resources. Specific suggestions to overcome the barriers faced by all groups were to create a best practices library for partners, put pressure on the National Science Foundation and other government agencies to increase funding and support for partnerships, create a glossy publication (like *Engineering, Go for It!*) that promotes partnerships that work, and reach out to K-12 and engineering societies to facilitate partnerships among various groups. Further, universities should become more involved with the K-12 schools in their districts, such as through a newsletter to the schools on opportunities for involvement. Additionally, engineering departments should encourage their professors to help write K-12 curricula and become involved in the classroom, offering promotion and tenure incentives for these efforts. Attendees agreed that partnerships among the very types of groups in the room at the Leadership Workshop produce positive results, but they determined that the education community must overcome the barriers of time and money for K-12 schools, promotion and tenure for university professors, and easily definable and measurable results for industry in order to move forward with additional productive collaborations.

Anecdotal evidence and a survey of the Leadership Workshop participants showed that the event was a huge success. Attendees found the discussions lively and engaging, and were excited to learn about the activities of other types of groups conducting K-12 engineering outreach. Additionally, the participants had time for networking and informal discussions, which helped facilitate energetic debate on a myriad of subjects crucial to K-12 engineering education. And finally, the discussions also helped formulate the guidelines contained in this paper.

V. What Are We Doing Now? A Summary of Current Outreach Programs

"The mission of this program is to introduce young girls to the discipline of engineering in hopes of encouraging them to join the profession. Our long-term goal is to increase the pool of female engineers."

-Response of outreach program leader in ASEE's 2003 outreach program survey

[10] "Why Janie Can't Engineer: Raising Girls to Succeed." Pat McNees. *Washington Post*. January 6, 2004: Page C09. Also, see http://www.patmcnees.com/work6.htm.

Statistical analysis of teachers' attitudes and in-depth discussions among K-12 experts, have demonstrated that there is a need for enhanced K-12 engineering education outreach. For many years—and especially in the last five years—many universities and other groups have embarked on ambitious outreach programs. Are these programs meeting the needs expressed by the teachers and experts? An ASEE survey of outreach programs shows that while the programs reach a lot of students and teachers to promote engineering education, the programs fall short of what is necessary.

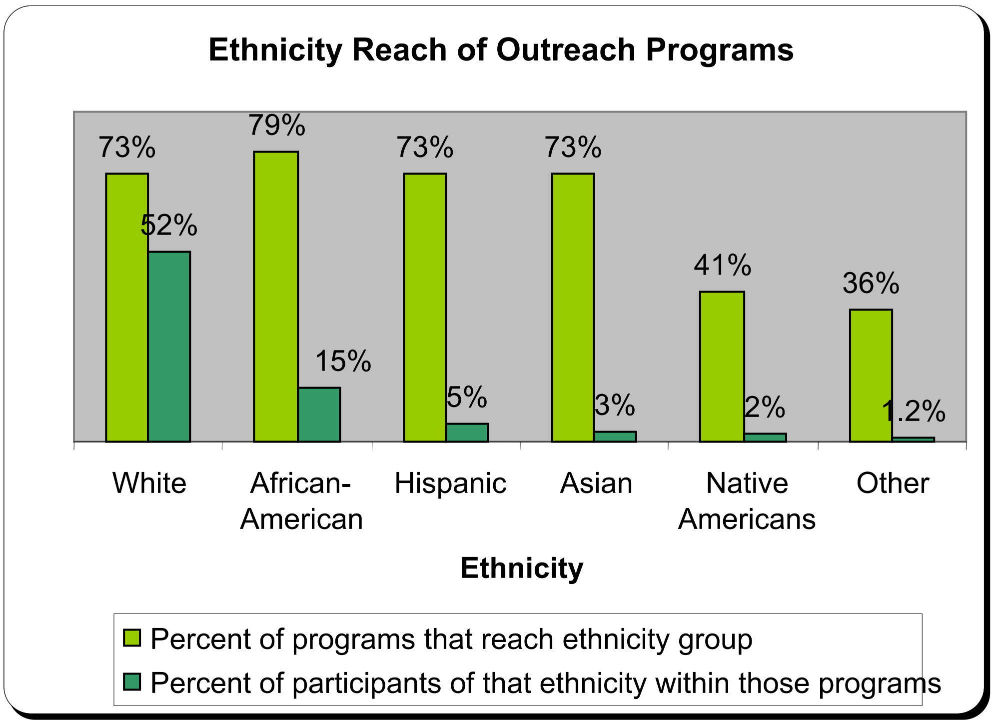
In the spring of 2003, ASEE surveyed almost 300 outreach program leaders to better understand the composition of their programs—the annual budgets, reach, expertise of instructors, and curriculum. Surveys were conducted online and had several open-ended questions to allow program leaders to provide detailed explanations with their answers. 66 program leaders responded to the survey.

While the earliest program among the responses started in 1956, the majority began in the last 15 years. 41% began in 2000 or later, while over 75% were founded between 1990 and 2002. The annual budgets for the programs ranged from $1,200 to $5 million, with the average annual budget at $410,485. 13% of the programs have budgets of $1 million or higher, while 38% have budgets between $100,000 and $1 million, and 18% have budgets of under $10,000.

Most of the programs reach a handful of students in their local area. However, the range is quite varied—one program reaches only one student per year, while another reaches 70,000. In general, however, the programs are small in scale—46% reach 100 or fewer students and 72% reach 1,000 or fewer students. Only four of the 66 programs have a reach of over 10,000 students.

The outreach programs do reach a wide variety of ethnic groups, but the majority of participants are still mostly white. Out of the 66 total responses to the survey, 44 answered with information on student demographics. An equal amount of programs, 32 out of 44, reach not only white students, but Hispanic and Asian students as well. That is, 73% of the 44 programs have at least one white, Hispanic or Asian student in them. 79% of the programs that responded with demographic information had at least one African-American student in them. 12 programs seemed to be specifically targeted to minorities, so reached no white students at all.

Taking a closer look at these results, however, reveals that despite the high percentage of outreach programs reaching many ethnic groups, the actual numbers of minority participants within these programs are low. Even though 79% of the programs reach African-American students, only about 15% of the participants are African-American. The same can be seen with 73% of programs that reach Hispanic and Asian students, respectively. Out of those programs, approximately 5% of the participants are Hispanic, and only about 3% are Asian students. The lowest numbers are seen with Native American students, where 41% of the programs reach Native American students, but only 2% within them are Native American. From the 44 outreach programs that provided demographic information, it is clear that they are dominated by white students. Out of the 73% of programs that reach at least one white student, 52% of the participants are white (See Graph 4). The story is the same for gender. 34 of the 44 programs reach both male and female students, while the other 10 are open only to females. Out of the 34 programs that reach both sexes, 54% are the participants are male and 46% are female. That is, the programs reach many different traditionally underrepresented groups, but the reach within those groups is smaller. Then again, with only 20% of engineering undergrads being female and 5.3% being African-American, the programs do reach a higher percentage of students from these groups than what is reflected in the current engineering population. Still, it is clear from these numbers that more can be done.



Graph 4

Further, over half of the programs also reach teachers, ranging from reaching one instructor to 1,500. Again, however, the scale is small—61% reach 100 or fewer teachers, while 85% reach 1,000 or fewer. Similar to the composition of the student participants, the outreach programs tend to reach mainly white teachers and more males than females.

The programs also reach into America's high schools more than they do the middle or elementary schools. 77% of the programs have high school students as participants, while 46% have high school teachers. This is contrasted with 49% having middle school students and 38% having middle school teachers, and 21% having elementary school students and 24% having elementary school teachers. Therefore, more can be done in the outreach efforts to pull in younger students and those who teach them.

The outreach programs utilize several different types of instructors. The programs generally have between 1 and 150 instructors, with Project Lead the Way being the outlier and boasting over 1,000 K-12 teachers. 33% of the programs have 8 or fewer instructors, while 22% have 30 or more. While 80% of the programs use a combination of engineering faculty, graduate students, undergraduate students, and/or others as instructors, 7% use only engineering faculty, 3% use only engineering graduate students, 3% use only engineering undergraduate students, and 7% use no one in engineering education to instruct the programs.

Collaboration was also seen in the curriculum design. 62% of the programs used a combination of engineering faculty, K-12 teachers, engineering specialists, and others to write the curriculum. However, the numbers for each type of curriculum writer are skewed toward engineering professors. 79% of programs used engineering faculty to help design the curriculum, while only 28% used K-12 teachers. Further, 21% of the programs used only engineering faculty to design the program. Partnering in writing the curriculum for these programs—especially with K-12 teachers—is one key area for improvement.

Analysis of current outreach practices demonstrates that a lot of good is being done. K-12 engineering outreach programs introduce many types of students and teachers to the world of engineering, and they do so through partnerships and collaboration between many groups. However, comments both from teachers in the attitudes survey and experts from the Leadership Workshop suggest that improvements can be made. Outreach programs can do a better job recruiting a more diverse and younger audience, and they can forge additional partnerships to write curricula and engage their participants. Indeed, the efforts of outreach program leaders so far should be applauded, while the ideas for improvement can be incorporated into recommended guidelines for K-12 engineering education.

VI. Where Do We Go from Here? Guidelines for K-12 Engineering Education Outreach

"We can provide that brighter future for our students."
-Teacher at the Leadership Workshop on K-12 Engineering Outreach

Education experts like to be visionaries, projecting ways to improve future education in the United States. ASEE has attempted to take a similar, visionary approach in its K-12 efforts. We have seen that there is a reason to be concerned about engineering education in our society, as the technological and economic future depends on it. We have identified both a statistical and a societal argument for the need for stronger engineering education at a younger age, and especially toward females and minorities. We have queried current teachers to determine their attitudes about K-12 engineering education and have found that most science and math instructors have overwhelmingly positive attitudes in general, but that they also believe many of their students, and certainly the females and minorities, are often shut out of an engineering education and career. We have heard from the K-12 experts—teachers, university professors, industry representatives, and others who attended the ASEE Leadership Workshop on K-12 Engineering Outreach, who all called for specific reforms in K-12 engineering education. Finally, we examined current outreach practices, to understand what is being done well—and what can be improved. All of the above has led us to one direction—a clear and concise set of ideas for moving the country forward in K-12 engineering education. The concerns of teachers and experts, the shortfalls of current outreach programs, and the vital importance of improving the knowledge of engineering concepts for all students, and especially younger students, females, and underrepresented minorities, have influenced the formation of six key guidelines for K-12 engineering education:

- *Hands-on learning*: Make K-12 science curriculum less theory-based and more context-based (hands-on), emphasizing the social good of engineering and demonstrating how it is relevant to the real world
- *Interdisciplinary approach*: Add a technological spin to all subjects and lessons, and implement writing guidelines in math and science courses
- *Standards*: Involve engineering in K-12 lessons that map to state standards for math and science. Further, states should follow Massachusetts and enact state standards for engineering
- *Use/Improve K-12 Teachers*: Engage more K-12 teachers in outreach efforts and curriculum writing, and increase teacher salaries to attract the best technological minds to teaching
- *Make Engineers "Cool"*: Outreach to urban schools and females more aggressively, and create more mentors and role models to attract these constituencies
- *Partnerships*: Create better incentives for all groups to engage in K-12 outreach (especially higher education and industry)

Taken as a group, the six guidelines provide a general sense of how to move forward in the K-12 world. Specifically, each idea answers the call of the K-12 community, with specific suggestions for improvement. Educators at the Workshop promoted hands-on learning and an interdisciplinary approach to engineering education, making engineering socially relevant to their students and integrated with other lessons. State standards are seen as a roadblock to implementing engineering, but by refocusing our ideas and actions, standards can be used for positive change both in the classroom and as a policy initiative. Teaching can be improved through a better certification process, higher and merit-based salaries, and by bringing engineers into the classroom. In the same vein, K-12 teachers need to be more involved in curriculum writing for lesson plans and outreach programs. Further, teachers can act as role models, but they should not be the only ones.

The engineering community needs to find better mentors and role models, making an engineering career "cool" and accessible for all constituencies, especially females and minorities. Finally, everyone in the K-12 community can do a better job of working together, creating partnerships between K-12 teachers and schools, universities, industry, and community organizations.

These six guidelines can be easily implemented in our classrooms and outreach programs by individual teachers. Those reaching students can adjust their lesson plans to make them more hands-on, and they can integrate engineering ideas into the liberal arts subjects. Teachers can also be proactive in making sure they and their peers are better prepared and more involved in curriculum writing and education policy. Educators can also do their part to make engineering "cool" by introducing positive role models, and they can forge partnerships with local organizations. Additionally, the best practices can be used in a more general sense as talking points for lobbying our public officials toward change. By refocusing our efforts along the lines suggested with these guidelines, we can answer the call of society to provide a better prepared, technologically savvy, and diverse workforce for years to come.

APPENDIX A

ASEE LEADERSHIP WORKSHOP ON K-12 ENGINEERING OUTREACH
ASEE Annual Conference
Salt Lake City, UT
June 19, 2004

PROGRAM

7:30-8:15, Registration & Continental Breakfast

8:15-8:30, Welcome & Introduction of Keynote Speaker
Duane Abata, ASEE President, Northern Arizona University

8:30-9:15, Keynote
John Brighton, Assistant Director for Engineering, NSF

9:15-10:15, Higher Education/Industry Views
Panelists: Dick Blais, Project Lead the Way
Martha Cyr, Worcester Polytechnic Institute
Ronald Rockland, New Jersey Institute of Technology
Gary Smith, Autodesk
Moderator: Melvin Robinson, Utah Department of Education

10:15-10:45, Coffee Break

10:45-12, K-12 Views
Panelists: Michael Lach, Chicago Public Schools
David Marshall, Project Lead the Way
Shelly Montgomery, Spring Branch (TX) Independent School District,
Mark Wallace, High Point (NJ) Regional High School,
Moderator: Ted Batchman, University of Nevada, Reno

12-1, Lunch & Brief Remarks
Sherra Kerns, ASEE President-elect, Franklin M. Olin College of Engineering

1-2, Mixed Panel of K-12, Higher Education & Industry Representatives
Panelists: Tom Erekson, Brigham Young University
Gayle Griffin, Newark Public Schools
Jim Johnson, Howard University
John Stuart, PTC
Moderator: Rod Custer, Illinois State University

2-3:45, Break-out Sessions, Rooms 150 C-F

NOTE: Your badge should have a colored sticker. ***Please attend the break-out session that corresponds to the color of this sticker.*** Attendees have been assigned to break-out sessions to provide for representation of all stakeholder groups participating in the workshop.

FORMAT:
Step 1, (20-30 min) – brainstorming in four sub-groups
Step 2, (30-40 min) – facilitators convene as panel to summarize ideas generated
Step 3, (30-40 min) – refine proceedings into report to deliver in next session

1. Green Panel Facilitators: Larry Genalo, Iowa State University
150 C Dave Mitchell, Microsoft
Diana Wiant, Centaurus (CO) High School
Doug Gorham, IEEE
Moderator: Laura Bottomley, North Carolina State University

2. Red Panel Facilitators: Patti Curtis, ASME
150 D Araceli Ortiz, Boston Museum of Science
Mike O'Hair, Purdue University
M*oderator:* Levelle Burr-Alexander, New Jersey Institute of Technology

3. Yellow Panel Facilitators: Teri Rhoads, University of Oklahoma
150 E Dale Merrell, Capital Center HS (OR) Technical Institute
Warren Hill, Weber State University
Christine Cunningham, Boston Museum of Science,
Moderator: Elizabeth Parry, North Carolina State University

4. Blue Panel Facilitators: Gary Ybarra, Duke University
150 F Aisha Lawrey, New Jersey Institute of Technology
Leann Yoder, JETS
Greg Dixon, US Coast Guard/FIRST
Moderator: Marion Usselman, Georgia Insitute of Technology

3:45-4:30, Reports from Break-out Sessions
Reporters: Laura Bottomley, North Carolina State University
Levelle Burr-Alexander, New Jersey Institute of Technology
Elizabeth Parry, North Carolina State University
Marion Usselman, Georgia Institute of Technology
Moderator: Rod Custer, Illinois State University

4:30, Closing Remarks of a Strictly Ceremonial Nature
Eric Iversen, ASEE

4:30-6, Reception & Exhibition, Room 250
Attendees will be invited to partake of food and drink, mix and mingle with their new friends, and browse among the displays set up by the sponsors of the workshop. Our thanks to:

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