Addressing broader impacts through K–12 outreach in materials education

Barbara M. Moskal and Laura Kosbar, Guest Editors

Researchers worldwide recognize the importance of inspiring the next generation of scientists through outreach activities. U.S. researchers have additional motivation in that many funding agencies are now requiring kindergarten through twelfth grade (K–12) outreach as part of fundable research plans. Unfortunately, many of these same researchers know little about the precollege educational community or about the educational system that supports that community. This special issue acts as a reference and provides pointers to the many opportunities available for materials education outreach, along with suggestions and advice on how both the novice and experienced researcher may contribute.

Introduction

The importance of educating the world's youth cannot be overstated, as they are our next generation of leaders, inventers, and technologists. Today's students, who are between the ages of 5 and 18, will be faced with a wide range of difficult technological challenges as adults, including energy generation, collection and storage, applications of nano- and biotechnology, and a host of legacy environmental issues. Their success in facing these challenges will be influenced by the strength of their educational foundation, as well as their inspiration and motivation to pursue careers in technical disciplines. Materials scientists and engineers, through outreach, can have a significant impact on students' development in these important areas.

It is often during the formative years that students develop an interest or aversion to specific fields, which can influence their career choices.[1–4] For students who have an interest in science, technology, engineering, and mathematics (STEM), their precollege years are crucial for establishing foundational knowledge. Recent studies indicate that in some countries, students' basic knowledge of mathematics and science has diminished relative to previous generations,[5–8] and many teachers are inadequately prepared to teach STEM.[9–15] In other countries, such as Singapore, the Republic of Korea, and Hong Kong, students are achieving top scores in both mathematics and science based on international comparisons.[16] One approach that has been used successfully to increase student interest and awareness in STEM is improving the education of both students and teachers through personal contact with practicing STEM professionals.[17,18] From an academic and industrial perspective, this is known as "educational outreach."

As an example of a successful outreach program, faculty and graduate students at the Colorado School of Mines designed a multi-pronged approach to increase the engagement of middle school teachers and their students in hands-on learning of science, mathematics, and engineering.[18]A series of programs involved intensive summer teacher training programs along with in-class follow-up and support over the course of the subsequent academic year. Faculty and graduate teaching fellows assisted the teachers with the incorporation of active learning in their lesson plans. They also became role models and examples of "working scientists" with whom the students could identify and interact. Several materials-oriented topics formed part of the program, including the energetics of chemical reactions, investigations of the properties of acids and bases, magnetics, polymers, and the dissection and investigation of materials used in "everyday" items from diapers to computers. Each activity was specifically designed to be linked to regional academic standards for mathematics and science.

During assessment of the programs, the teachers indicated their participation resulted in increases in the following: (1) real-world and interdisciplinary examples that they presented during classroom instruction, (2) technology used in the

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classroom, (3) qualifications of teachers in the content area taught, and (4) resources available for classroom use. As one teacher commented, "The information I gained in the summer workshop renewed in me a passion to learn, research, and investigate the world around me." The programs also had an impact on middle school students, as a classroom evaluator noted, "Students are eager to have the graduate teaching fellows teach the classroom lesson, being assured that the lesson will be hands-on and relevant to their life." Students in the treatment groups also performed slightly higher on Colorado's Student Assessment Program when compared to the district average. This is just one of many examples of outreach programs available throughout the world.

Professional organizations and societies also promote and sponsor a wide range of outreach efforts. The National Professional Society for Engineers in the United States created National Engineer's Week in 1951, with the purpose of encouraging students' interests in engineering and engineering professionals' involvement in educational outreach. In 2005, this program was expanded globally, an example of which is provided in the sidebar by Wynne and Gable. The American Chemical Society developed a similar event called National Chemistry Week. Both societies dedicate additional resources, person power, and honors to outreach activities related to these events. The Material Research Society (MRS) created the traveling science exhibit, "Strange Matter," which highlights materials science through exhibits designed for science museums, as well as through its website (http://www.strangematterexhibit.com/where.html). Each of these events and activities is designed to bring the joy and wonder of science and engineering to the attention and experience base of young learners.

Materials scientists in industry as well as academia have increased their focus on reaching out to students in their communities. In many cases, well-organized collaborative efforts exist, as exemplified in the sidebar by McMaster. Researchers have also become involved in the development of engaging and topical curricula for students and for teacher training programs, as demonstrated by "Project Lead the Way" (http://beta.pltw.org/educators-administrators/our-programs). As these examples illustrate, many professionals understand the value of educational outreach and are already actively involved. Others, however, may recognize the importance but may not know how to get involved.

This issue consists of five articles that address the broader impact of pre-college outreach within the materials research community. The primary purpose of this issue is to illustrate both the important work that is being done as well as the potential of outreach for expanding the materials science community to include the next generation. To the inexperienced researcher, this issue offers advice and examples for planning and incorporating outreach in their research efforts. For the more seasoned investigator, this issue offers an overview of the diverse and successful programs that are already under way and identifies resources that are available to augment new or existing outreach efforts.

In the development of this issue, our aim was to bring attention to outreach as it occurs around the globe. Outreach programs are by nature strongly influenced by the educational

IBM's international outreach efforts

James J. Wynne and Lisa Gable (IBM)

IBM has been a corporate affiliate since 1990 of National Engineers Week's (which in the U.S. is organized by the National Professional Society for Engineers) annual "Discover Engineering" campaign of technical education outreach. IBM employees led hands-on activities in science and engineering, including testing materials properties by constructing "skyscrapers" from newspaper, "bridges" from spaghetti and gum drops, and creating "slime" from borax and glue. For instance, they explained how integrated circuit chips are designed and fabricated for use in video game systems, such as the Nintendo Wii, Sony PlayStation 3, and XBox 360. As of 2005, this effort has included participants at a number of international sites, including China, India, Israel, Japan, Argentina, Brazil, Poland, Portugal, Romania, Russia, Slovakia, Spain, and Turkey. In recent years, IBM has recruited more than 5,000 volunteers annually who connected with more than 200,000 students per year. For more information, visit http://www.watson.ibm.com/leo/ or contact jjwynne@us.ibm.com.

IBM employees have also organized "Exploring Interests in Technology and Engineering (EX.I.T.E.)" summer camps specifically for middle school girls. Approximately 30 camps involving more than 600 girls were offered in 2010, including locations such as Malaysia, Turkey, Portugal, Israel, United Kingdom, Canada, India, and the United States. Camp sessions include LEGO-based robotics, polymer science (including creating cross-linked polymers from glue and isolating DNA from strawberries), states of matter, kitchen chemistry (including identifying acids and bases in the home and the materials properties of non-Newtonian materials such as cornstarch and water), and electronics. Since the inception of these camps in 1999, more than 10,000 girls have participated.

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Industry and academia collaboration

Rick McMaster (Austin, TX)

Austin, Texas, is a large city with vast technical resources, including hundreds of technology companies of all sizes, as well as the University of Texas at Austin. Many Austin-based professionals are interested in volunteering their time to support K–12 students, and some classrooms receive multiple offers for support, while others may not have the opportunity to participate. In response, a group of professionals who are passionate about encouraging students to study mathematics and science formed the Central Texas Discover Engineering steering committee. In its nearly 20 years of existence, the mission of the committee has been "to encourage school children in central Texas to pursue technology careers by providing role models from the local engineering community." This group includes representatives from three professional societies—American Society of Civil Engineers (ASCE), Institute for Electrical and Electronics Engineers (IEEE), and Society of Women Engineers (SWE)—several large companies—3M, AT&T Labs, Applied Materials, IBM, Intel—the University of Texas, and a local non-profit, Skillpoint Alliance. The steering committee has coordinated visits of technical professionals to hundreds of classrooms. Professionals from approximately 50 firms participate, reaching more than 20,000 students annually. This steering committee exemplifies the impact that coordination between diverse professional participants can have in expanding educational outreach efforts. For more information, visit http://www.centexeweek.org.

system, traditions, cultures, and needs of a particular nation or state. While at times we adopt the convenient acronym "K–12" (referring to students between the ages of 5 and 18—the age range of formal public education in the United States) to refer generically to students in pre-college education systems, the reader will find that the examples included in this special issue seek to highlight the efforts of the international materials community.

The article by Reed-Rhoads discusses a critical issue in K–12 outreach: How do we measure success? Success in the Reed-Rhoads article refers to the extent to which the outreach activity has had its desired impact on teachers' and students' knowledge, understanding, and attitudes. Reed-Rhoads illustrates the assessment process using the engineering design cycle, a process that is known to both engineers and scientists. This article focuses on what materials researchers need to know as they develop assessment plans for their educational outreach activities. Through this article, Reed-Rhoads lays the foundation for how to develop an assessment plan through the early establishment of the program's goals, objectives, and outcomes. Guiding questions are provided throughout the article, questions that lead the reader through the process of developing an outreach assessment plan. Reed-Rhoad's discussion highlights and defines four potential outcomes—cognitive, affective, behavioral, and metacognitive—and three forms of assessment—formative, summative, and interim. She also discusses the differences between qualitative and quantitative measurement, such as measures via rich description or numerical summaries, respectively, and the legal requirement of the human subjects' review. All of these concepts need to be considered in order to develop, design, and implement an effective materials outreach assessment plan.

The article by Zenner Petersen highlights what many researchers view as the primary target audience for outreach—K–12 students—and how to get to know the target audience prior to defining an outreach effort. Demographic differences are highlighted, such as age, race, and gender, as well as the potential impact of culture and background. This article provides examples of the various outreach activities that are already under way in materials science research. She highlights the importance of passion and enthusiasm—both that of the researcher and the participating students—in the construction of effective outreach programs. Through this article, the reader discovers that outreach can occur in a variety of settings (classrooms, museums, libraries, community programs, afterschool or summer programs) and can include partners from education (K–12 and academia), industry, professional societies, and local community groups. Given the diversity of efforts that are under way, this article acts as a broad survey of the possibilities rather than as an in-depth study of individual efforts.

Marshall approaches the subject of outreach from a different perspective. His article discusses the translation of the theory of outreach to practice. Marshall provides examples of how others have overcome a major challenge of outreach: converting complex scientific ideas into understandable K–12 activities. Many researchers struggle with the concept of sharing research material with a K–12 audience in a manner that the students can both understand and enjoy. This article discusses the translation of research into outreach materials by "distilling" key and relevant aspects that the students will relate to rather than just "diluting" the science to the perceived level of the audience. Marshall offers specific suggestions on how to engage an audience in the exploration as well as the facts related to materials science content. Resources that support the outreach

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efforts of the materials research community are highlighted, including science communication workshops, education and outreach symposia, outreach guides, partnership assistance, kits, and other resources.

Teachers are also an essential component of outreach. Teachers have direct access to, and influence on, students on a daily basis. The article by Nucci discusses outreach that targets teachers as the primary audience. The primary focus of this article is on programs that develop teachers' knowledge of mathematics and science as these subjects relate to materials research. This article illustrates the many existing programs and resources for outreach, including those available in which teachers partner with academia, industry, and national laboratories, such as research experiences for teachers (RET), teacher institutes organized by science museums and National Science Foundation Engineering Centers, and collaborations to provide laboratory equipment and resources. A key component of this discussion is the importance of connecting materials that are designed for the classroom with the participating school system's requirements.

As outreach continues to expand, electronic and web-based methods are becoming more useful to increase the impact of individual outreach efforts. As discussed in the article by Polycarpou, technology allows content to be accessible to students and teachers in rural regions and in countries beyond where it was originally developed. The article discusses educational software that is already available for use in materials science outreach programs such as chemical reaction simulations, virtual microscopes, or games that introduce players to the use of materials in everyday life. Software includes programs designed for students and teachers. Additionally, technology has made it possible for scientists to "virtually" visit classrooms through interactive video links. Through the National Lab Day website (http://www.nationallabday.org/), teachers in the United States can request online assistance from a scientist to support their K–12 classrooms. This article provides an extensive resource list and not only acts as a survey of what is available but also as a vision for what is possible.

The reader will notice that throughout this special issue, sidebars are included with examples of outreach in materials science research. These sidebars provide "real" examples of materials science outreach in action. The sidebar by Strong highlights outreach at a university that is designed to integrate assessment, teachers, students, activities, and technology. Through the included articles and sidebars, we seek to provide readers with a glimpse of the important work that is already under way as well as guidance and inspiration for the expansion of this work (see the sidebars by Chang and Weertman). We believe this issue has something to offer both researchers experienced in K–12 outreach, as well as those that are in the beginning phases of such involvement.

Integrating outreach, assessment, and technology with teacher and student activities

Jennifer Strong (Colorado School of Mines)

The National Science Foundation (NSF)-funded *Renewable Energy Materials Research Science and Engineering Center* (NSF, DMR-0820518) at the Colorado School of Mines (CSM) is involved in a K–8 outreach partnership directed at maintaining student interest in science and engineering through hands-on activities in their classrooms. The project is a collaboration with the Center for Assessment in science, technology, engineering, and mathematics (STEM) at the Colorado School of Mines, the National Renewable Energy Laboratory, the NSF funded K–12 Learning Partnerships (NSF, DGE-0638719), and the Bechtel K–5 Educational Excellence Initiative. The program focuses on teacher training beginning with a two-week summer workshop for the participating teachers. During these summer workshops, teachers receive information and activities drawn from energy, energy-efficient materials, and alternative and renewable energy concepts. The goal is to use energy concepts to generate enthusiasm for STEM activities in teachers and their students. Activities incorporate electricity and magnetism, circuits, conductors, insulators, batteries, solar cells, fuel cells, wind energy, geothermal energy, and hydro energy. During the academic year, these same teachers are assisted by scientists, researchers, and graduate students as they implement these activities in their classroom via classroom visits. To support remote communication with a rural school system, Meeker County, ExxonMobil has funded an interactive video link between the district and CSM. Through this link, faculty members are able to connect to a classroom without leaving the campus. Formative and summative assessment plans for each of these activities have been developed and implemented to measure cognitive, affective, and behavioral domains of student and teacher learning. To learn more about these programs, the following websites are available: http://mcs.mines.edu/Research/k12-partnership/new/ and http://mcs.mines.edu/Research/bechtel/new/.

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Materials World Modules program

Robert Chang (Northwestern University)

Materials education offers exciting opportunities for depth of learning across disciplines. Established in 1993 with funding from the National Science Foundation, the Materials World Modules (MWM) program has developed a series of supplemental instructional modules that bring the latest materials research into pre-college classrooms and engage students in the work of materials scientists and engineers.

Materials researchers at Northwestern University and science teachers jointly authored 16 modules, including polymers, ceramics, composites, biosensors, dye solar cells, nanotechnology, and environmental catalysis. Each module has three parts: a "hook" that captivates student interest and inspires inquiry; exploratory activities that provide background central to the topic; and design projects that challenge students to apply what they have learned by creating functional prototypes from the materials at hand. This hands-on approach demonstrates the relevance of materials science, inspires interest in materials-related careers, increases student confidence and enthusiasm, and builds essential workforce skills such as creativity, critical thinking, innovation, and teamwork. Recent modules are linked to web-based animations, simulations, and games that support student learning.

Because the modules last just two weeks and are closely aligned with national learning standards, they can be easily inserted into a variety of science, technology, engineering, and mathematics (STEM) courses and have been successfully used by more than 50,000 students in the United States. The program has also been used in Mexico since 2005. National field tests have shown that MWM increases STEM performance, regardless of gender, socio-economic setting, or level of teacher experience.

The modules are an ideal and cost-effective way for university and laboratory outreach programs to reach local classrooms. Each module includes a teacher's edition, student manuals, and a classroom kit containing basic materials for a class of 24 students. Teachers can register for professional development workshops and join an online community. For more information, visit www.materialsworldmodules.org.

ASM Materials Camps

Julia Weertman (Northwestern University)

This summer, about 700 high school students will be spending up to a week at an ASM Materials Camp. Under the supervision of experts and volunteers, they will carry out hands-on experiments that illustrate exciting and remarkable behavior in various types of materials. For more than 10 years, the materials professional society ASM International has run Materials Camps for students as well as for high school science teachers. As a result of vigorous fund raising efforts by ASM, the camps are free to attendees. Since 2000, the ASM Materials Educational Foundation has spent more than a million dollars on the camps, graduating 2,200 high school students and 800 teachers, and has given more than $600,000 in scholarships. Materials Camps are held across North America, with international camps scheduled in France and India.

With the goal of introducing materials science into high school curricula, Materials Camps have also been set up for science teachers. The program is based on past experience in the areas of curriculum development, teacher training, and student programs in materials science developed at the University of Washington and Edmonds Community College (Lynnwood, Washington) and supported by the National Science Foundation. During the one-week workshops, teacher participants learn the basics of materials science technology as taught at the high school level. They work hands-on with various classes of materials, and develop an appreciation for the importance of these materials to modern life.

These Materials Camps for students and teachers are leading to the introduction of full-year courses on materials in some schools. In Albuquerque, more than 500 high school students now take a materials course annually. Along with several partner societies, ASM International has embarked on a plan for the adoption of materials science courses in additional school districts. The goal is to reach tens of thousands of young people annually, not merely the several hundred now reached.

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