TURNING CUTTING-EDGE RESEARCH INTO SECONDARY CURRICULUM

Greta M. Zenner¹, Wendy C. Crone¹,², J. Aura Gimm³, Ken W. Lux¹, Paul M. Voyles¹,⁴, Nicholas L. Abbott¹,², Cindy G. Carter⁶, Anthony P. Cina⁷, Ann Pumper Comins⁸, Johan Tabora⁹, Pamela Tuchscherer¹⁰, Tyson Tuchscherer¹¹ and P. John Whitsett¹²

¹Materials Research Science and Engineering Center, University of Wisconsin-Madison, 1550 Engineering Drive, Madison, Wisconsin 53706-1608; ²Department of Engineering Physics, University of Wisconsin-Madison, 1500 Engineering Drive, Madison, Wisconsin 53706-1687; ³Department of Biomedical Engineering, Duke University, Durham, North Carolina 27708-0281; ⁴Department of Materials Science and Engineering, University of Wisconsin-Madison, 1509 University Avenue, Madison, Wisconsin 53706-1595; ⁵Department of Chemical and Biological Engineering, University of Wisconsin-Madison, 1415 Engineering Drive, Madison, Wisconsin 53706-1691; ⁶Stoughton High School, 600 Lincoln Avenue, Stoughton, Wisconsin 53589; ⁷O'Keefe Middle School, 510 South Thornton Avenue, Madison, Wisconsin 53703; ⁸James Madison Memorial High School, 201 South Gammon Road, Madison, Wisconsin 53717; ⁹Northside College Preparatory High School, 5501 North Kedzie Avenue, Chicago, Illinois 60625; ¹⁰Gearhart School, 1002 Pacific Way, Gearhart, Oregon 97138-4299; ¹¹Daly Middle School, 220 South H Street, Lakeview, Oregon 97630-1858; ¹²Fond du Lac High School, 801 Campus Drive, Fond du Lac, Wisconsin 54935.

ABSTRACT

Traditional science classroom activities rely on topics and experiments that are distant from the forefront of scientific research. As a result, students may view science as stagnant and far removed from real life. Through a National Science Foundation-funded Research Experiences for Teachers (RET) program, the University of Wisconsin-Madison (UW) Materials Research Science and Engineering Center (MRSEC) works with secondary teachers to transform cutting-edge research in nanoscale science and engineering into curriculum that is appropriate for middle- and high-school classrooms. This benefits everyone involved: teachers learn about innovative science and the process of research; UW MRSEC personnel learn about science education and the state of today's schools; and students get to test and engage with new curriculum about breakthrough research. In the summer of 2004, our RET participants conducted research on and developed curriculum about “smart” papers with microencapsulation technology, fuel cells, nano biosensors and liquid crystals, glassy metals, and Wells polyhedral models.
INTRODUCTION

The University of Wisconsin-Madison (UW) Materials Research Science and Engineering Center (MRSEC) offers teachers the opportunity to conduct cutting-edge research in nanotechnology and materials science and to create classroom curriculum based on that research. This National Science Foundation (NSF)-funded Research Experiences for Teachers (RET) program at UW provides K-12 teachers with support to participate in a 5-week, full-time summer program. As RET fellows, teachers work with MRSEC faculty, post docs, staff, and graduate students to develop curriculum and conduct necessary related research. The RET participants also collaborate with the RET program director and each other as they learn about the process of science, create grade-level-appropriate classroom materials, and explore the Nanoworld.

PROGRAM OBJECTIVES

The RET program furthers the education objectives of our MRSEC by bringing secondary teachers into contact with both the content of cutting-edge research in materials science and engineering and the process by which this research is conducted. An important objective in the UW MRSEC is to continue to provide opportunities for teachers to carry out original research and to assist them in bringing their newly developed knowledge and enthusiasm back to their classrooms. By “educating the educators” in this way, there is a great amplification of knowledge and appreciation for modern materials science and engineering and its instrumentation and methods. In addition, by working with area teachers, UW MRSEC faculty and students learn about the state of education in today’s schools, the challenges of being a secondary teacher, and the strategies used to simplify complex scientific information. Faculty often use these experiences as background when they design new outreach materials or integrate additional outreach efforts into new funding proposals.

Thus, by working with a cadre of teachers trained in the RET program, we believe that we will develop a regional education infrastructure that will lead to the realization of many of the UW MRSEC education, outreach, and human resource objectives. Using UW MRSEC resources, we have supported the dissemination of RET results through teacher presentations at conferences and workshops, such as the annual Wisconsin Society for Science Teachers conference. After the classroom materials are tested, we also work with teachers to develop web-based versions of their materials, which are then disseminated broadly on the UW MRSEC website\(^1\).

Through our RET program and an NSF-funded Internships in Public Science Education (IPSE) program\(^2\), which also partnered UW MRSEC with K-12 teachers, we believe we have identified an effective method for research-based science education that utilizes a two-step adaptation approach. In the first step, UW MRSEC and IPSE personnel modify experiments based on state-of-the-art research to make them appropriate for middle- and high-school-level classrooms and laboratories. This has been done for numerous experiments already, as is evident from our web-site\(^3\). In the second step, middle- and high-school teachers learn about one of these cutting-edge research topic areas and collaborate with UW MRSEC and IPSE personnel to adapt the college- and middle-school-level materials for their own secondary-school science classrooms\(^4\). Through this process, RET fellows have the opportunity to conduct laboratory experiments based on state-of-the-art research while developing exciting secondary-school curricula based on leading research in advanced and nanoscale materials.

Several strategies are used for recruiting applicants for our RET program, the first being our past successes. Many of our former middle- and high-school teacher collaborators are enthusiastic to continue working with us for multiple summers as part of RET, and additional teachers apply to our program each year through unsolicited applications and word-
of-mouth recommendations. We regularly receive unsolicited applications from teachers who have heard about our program and have visited our RET web-site. In addition, three NSF-funded projects at UW have been ideal for making connections to local middle and high schools. The UW MSREC works closely with our GK-12, Math Science Partnership, and IPSE programs, all of which have established valuable links to southeast Wisconsin K-12 science teachers. A final recruitment strategy utilized a listserv maintained by teachers involved in the Wisconsin Science Olympiad, which was held on the UW campus in spring 2004. Teachers are selected with an eye to sustained involvement past the 5-week program. Over the past several summers we have supported 3-7 middle- and high-school teachers from a range of disciplines, including physics, technology, mathematics, and chemistry. The majority of our teachers have been based in Wisconsin, but several have also joined us from other states, including Illinois and Oregon.

PROGRAM ACCOMPLISHMENTS

Our RET program objectives are to provide professional development for secondary-school teachers in science and engineering topics and to create instructional materials for middle- and high-school classrooms using the theme of nanoscale materials and interfaces. In recent years UW MRSEC RET has worked with nine secondary-school teachers. In addition to engaging these teachers with current research in nanoscale science and engineering on the UW campus, the teachers have also created teaching modules related to advanced and nanoscale materials for their classroom. With the assistance of UW MRSEC faculty and staff, RET teachers have developed and tested modules on topics such as shape memory alloys, light-emitting diodes, fuel cells, smart papers, liquid crystals, and ferrofluid. They have also designed modules about how scientists use x-ray diffraction and scanning probe microscopy to know the arrangement of atoms in a material. For each content area, the teachers and scientists paid attention to connecting the modules to current middle- and high-school curricula and to making the materials easy for other teachers to adopt. The modules have student and teacher versions of the activity sheets, information on alignment with national science\textsuperscript{5} and technology\textsuperscript{6} education standards, references, glossaries, background information, follow-up questions, sample lesson plans, and more.

A few select projects from the summer of 2004 are discussed in more detail here.

Fuel Cells: Fuel cell catalysts are often constructed of nanoscale-sized particles to maximize the exposed surface area. Low-temperature fuel-cell electrocatalysts are generally composed of expensive precious metals such as platinum and/or ruthenium. In order to maximize the exposed surface area, and hence power output, per unit weight of the electrocatalyst, the metals are utilized as powders comprised of nanoscale particles. Two teachers developed two modules on electricity, batteries, and fuel cells, one for the middle-school level and one for the high-school level. With the help of a UW MRSEC post doc and a Research Experiences for Undergraduates (REU) student, they developed a method to make a working potato fuel cell – the first of its kind that we know of! The potato fuel cell provides a wonderful analogy to the potato battery, which allows for directly comparing and contrasting these two methods of producing electricity.

Smart Paper: Ink-filled microcapsules on the surface of “smart” paper burst with the application of heat, pressure, or chemical changes, thus streamlining the printing process. Carbonless copy papers are smart papers that use capsule rupture to initiate a reaction that produces color on paper. This exciting topic incorporates a number of physics and chemistry principles and introduces concepts of micro- and nanotechnology. For UW MRSEC, this topic also has the advantage of being connected to Wisconsin industry (Appleton Paper in northern WI has been a partner in this project.).
UW IPSE students developed relevant middle-school level activities, but the advanced nature of much of the related content also makes smart paper appropriate for a high-school audience. One of the RET fellows developed a teaching module on smart papers for the high-school level, which allows for exploration of more advanced topics such as microencapsulation, colloid chemistry, dye precursors, and reagent layers. With the help of a UW MRSEC post doc, the teacher created several new inquiry-based activities about how smart papers work that requiring student preparation of their own microcapsules and student experimentation to determine the force needed to rupture the capsules.

The Atomic Structure of Metals: A material’s properties, such as strength or magnetism, depend upon its atomic arrangement. The atomic structure of metals can be understood mostly in terms of packing of different size spheres. Most metals are crystals, meaning that the spheres pack in a regular array, like eggs in an egg carton. The structure of amorphous (disordered) materials, such as metallic glasses adds an exciting component to activities on atomic structure. Our past work on the topic of atomic packing incorporated Legos®, but this approach does not readily lend itself to exploration of amorphous materials. One of the RET teachers developed an interactive middle-school module that explores the packing of hard spheres using ping-pong balls as a window on the atomic structure of metals and glassy metals for middle school students. With the help of a UW MRSEC faculty member, the teacher created four activities on packing in 2D, disordered packing, and the influence of multiple atomic sizes on packing. In addition to creating a hands-on activity that involved logic and visualization skills, the RET teacher also created a teacher’s guide for the activities that included a background material packet, a list of connections to curriculum standards, student question sheets, a student assessment tool, and a resource list.

INTEGRATION INTO THE K-12 CURRICULUM AND DISSEMINATION

Preparation of classroom-ready modules is an expected outcome of the projects described above. RET fellows are expected to adapt their research projects for integration into their classroom curriculum and to identify on-going components of the research that can be carried out with their students during the academic year. We envision this process as creating an infrastructure for continuous teacher professional development, maintaining ties with our own research and education efforts and encouraging secondary-school teachers and students to become interested in materials science research. By providing the RET-developed modules and movies on the UW MRSEC website, we create opportunities for teachers and students at other locations around the country and the world to make use of the materials related to nanoscale science and engineering.

Our RET participants are also encouraged to present the curriculum they have created at teacher professional conferences. For example, support is regularly provided for teachers to present their work at venues such as the Wisconsin Society of Science Teachers annual convention.

CONNECTIONS WITH OUR REU SITE ACTIVITIES

Research Experiences for Undergraduates (REU) students have been eager, effective contributors to the development of our instructional materials, including laboratory and demonstration experiments. Many of these experiments have been incorporated into the curriculum at UW and other college campuses. Many REU students have also been co-authors of peer-reviewed papers and kits resulting from UW MRSEC education and outreach. For example, in summer 2004, our REU student contributed to a paper about a fuel cell research and to a Spanish translation of one of our pre-existing kits. In each case, the REU students
performed considerable research, reflecting the need to adapt work described in original research publications for optimized curricular use. We have had RET and REU participants work jointly on several projects, like fuels cells, and substantial synergy has resulted from this form of collaboration. In the research component of the effort, there is teamwork associated with learning new concepts and techniques, and in the module development component, REU students provide valuable feedback on drafts prepared by RET participants.

ASSESSMENT

Our assessment efforts include entrance and exit surveys of RET teachers to help us understand their expectations, to determine what parts of the experience need to be modified to enhance the program’s impact, and to assess the effect of the program on its participants. These assessment tools consist of pre- and post-surveys that are part of a national effort directed by the national RETnetwork, and of an additional post-survey composed by UW MRSEC staff. The national surveys assessed the impact of the program on the teachers and their careers, while the in-house survey asked for evaluations of the RET program itself and for suggestions for improving the program for future participants.

Results showed that the teachers found working collaboratively with the other teachers to be extremely helpful for brainstorming, solving problems, and learning from each other. Teachers reported mixed feelings about the structure of the program; some wanted more structure (e.g., more than the one or two group meetings per week), while others wanted less structure (e.g., fewer group meetings). Our RET program focuses primarily on curriculum development, a feature that again produced mixed results. Some teachers were happy with the balance between research and curriculum development, while others indicated that they would have liked more time for research. Several teachers commented that the program could be improved by ensuring that chemicals and materials were ready when the teachers arrived to ensure that less time is wasted during the short five weeks.

In addition to the teacher surveys, surveys were administered to the faculty and post doc mentors of each RET participant. Mentors completed one questionnaire from the national RETnetwork that gathered information about the impact of the teacher on the mentor’s research and lab environment. Mentors also completed an informal, in-house survey that evaluated the RET program itself and asked for suggestions for improvement. The mentors were in general very pleased with their RET fellows and the work they did. A helpful suggestion for improving the program was to provide the teachers with more extensive library training to ensure that they would be able to move beyond strictly web-based resources and also utilize academic journals and books.

Throughout the academic year, the RET program coordinator maintains contact with the participants through e-mail correspondence and jointly attended conferences. This provides longitudinal data important for helping us to determine what aspects of their work are eventually incorporated into their professional and teaching activities.

CONCLUSION

Through the UW MRSEC education efforts, we have many years of experience working with middle- and high-school teachers from the region and around the country who have expressed interest in materials science and nanotechnology. The enthusiastic response of summer 2004 RET teachers and their students has given us confidence in our model of teacher professional development. By taking advantage of the opportunity the RET program affords to integrate exciting developments in nanoscale science and engineering research directly into the secondary-school curriculum, we believe we are positively impacting teacher and student experiences.
ACKNOWLEDGEMENTS

In addition to the mentors included as co-authors on this paper, we would like to acknowledge our past RET mentors - Art Ellis, George Lisensky, Amy Payne, and Eric Voss - for their contributions to the program. We would also like to thank Fiona Goodchild for her assistance with assessment and her advice on how to create a more effective RET program. This work is funded by the National Science Foundation through a Research Experiences for Teachers supplement to a Materials Research Science and Engineering Center grant (DMR-0079983). The associated Internships in Public Science Education program is also supported by grants from the National Science Foundation (DMR-0120897 and DMR-0424350). This work was also supported by the National Science Foundation through a CAREER Award to Prof. Paul Voyles (DMR-0347746).

REFERENCES


