INTEGRATING MATERIALS SCIENCE INTO THE HIGH SCHOOL CHEMISTRY CURRICULUM

Jeremiah J. Neubert[Ψ†], Cynthia G. Widstrand[Ψ‡], Ann M. Pumper[*], C. Bruce Swanson[*], and Arthur B. Ellis[‡]

[†]Department of Mechanical Engineering, University of Wisconsin-Madison, Madison, Wisconsin/ [‡]Department of Chemistry, University of Wisconsin-Madison, Madison, Wisconsin/ [*]James Madison Memorial High School, Madison, Wisconsin

Abstract

The focus of this project was to provide secondary chemistry teachers with creative, inexpensive, hands-on, minds-on teaching materials to introduce materials science into the curriculum. Three teaching modules were developed around an existing kit, "Exploring the Nanoworld". The first module, "Memory Metals", explores some of the unique properties of Nitinol along with its applications. The second module, "X-ray Diffraction and Scanning Probe Microscopy," uses two techniques for demonstrating the existence of atoms and determining their relative positions. Finally, a module on "Light Emitting Diodes" (LEDs) shows students how trends in the periodic table can be used to design these versatile light sources. Each unit is aligned with the National Science Education Standards and is accompanied by curriculum suggestions, sample lesson plans, and unit assessments. Background information for the teacher and student is included, along with investigations, demonstrations, and laboratory experiments. All three of the modules have been field-tested; teacher and student evaluations of the modules have been positive.

Introduction

High school science teachers are always in search of new and interesting ways to teach chemistry. The topics of solid-state chemistry and materials science provide engaging examples for the classroom, but

[Ψ] National Science Foundation GK-12 Teaching Fellow many teachers lack a detailed knowledge of this subject matter. In an attempt to address this need, three classroom teaching modules were developed. The modules build on the existing "Exploring the Nanoworld" kit created by the National Science Foundation-funded Materials Research Science and Engineering Center (MRSEC) on Nanostructured Materials and Interfaces at the University of Wisconsin-Madison (UW). The modules were constructed so that they could be added in part or in their entirety to the curriculum.

The modules, collectively entitled "A Teaching Companion to Exploring the Nanoworld", take into consideration the importance of state and national educational standards. The modules are focused on inquiry-based learning in which the students themselves drive learning by formulating hypotheses and testing them[1].

The goal of the "Exploring the Nanoworld" kit is to explain materials science and engineering concepts at the atomic level through hands-on activities that are engaging and understandable by the general public[2]. The kit includes a piece of Nitinol wire, a LED, a piece of fiber optic cable, a refrigerator magnet, a magnifying glass, and a picture book that leads the user through a series of activities that employs these items.

In addition to the MRSEC, two other NSF-funded programs permitted conversion of the kit to classroom-ready instructional materials. The Research Experiences for Teachers (RET) program provided resources for teacher professional development, allowing high school teachers to participate in the creation of these instructional materials. The "K-Through-Infinity" GK-12 program at UW enabled two graduate student teaching fellows, one from chemistry and one from engineering, to work with the high school teachers and MRSEC personnel to develop curriculum materials[3].

Development of the Teaching Companion

Beginning in the summer of 2000, the high school teachers, graduate students and faculty member comprising the development team met at roughly 2-3 week intervals to prepare the modules in draft form. The high school teachers would typically develop the format for presenting the work to their students and colleagues and receive feedback from the university partners and other individuals whose expertise was needed. In the course of preparing their materials, the high school teachers often had questions or needed resources. These needs were then addressed by the graduate students. Each module was revised several times. The teachers also assessed the feasibility of a variety of laboratory activities. While the modules were being field tested during the 2000-01 academic year, they were also made available to other high school and college teachers for additional review.

A principal objective in designing the modules was to provide high school teachers with an easy and exciting way to introduce materials science into the classroom using current technology. The Teaching Companion uses activities that require students to take an active role in their learning. An introduction to the collection of the modules is presented in overview form and with connections to the aforementioned education standards.

The modules are teacher-friendly by design. Each module begins with a one-page outline called Curriculum Suggestions. This is followed by a 50-minute lesson plan. The next section contains an overview of the module and the background information needed to use it. A section of handouts and instructor notes for all the activities follows the Overview. The final section includes a test for assessing student learning following use of the module.

Memory Metal Module

The first module makes extensive use of the shape memory alloy Nitinol, a nickel-titanium alloy. An initial experiment that highlights the fascinating properties of this solid involves asking students to bend a Nitinol wire and then immerse it in hot water. They are startled to find that the wire suddenly returns to its initial linear shape. This observation naturally leads to a discussion of phase changes in matter (Nitinol undergoes a martensite-to-austenite phase transition with heat or stress.) and some of the interesting physical properties associated with the different phases. Through a series of investigations, which include use of the Institute for Chemical Education's Solid State Model kit, students rationalize the chemical and physical properties of the material[4]. This knowledge helps students solve a design problem proposed in the Teaching Companion, which serves to contextualize student learning.

Scanning Probe Microscopy and X-ray Diffraction Module

The second module takes the techniques of scanning probe microscopy and x-ray diffraction and explains them in a hands-on manner. These techniques are extensively used for determining the relative positions of atoms. To illustrate scanning probe microscopy, a probe strip is cut from the edge of a common refrigerator magnet. When the probe is scanned across the unprinted side of the magnet, students experience different magnetic interactions depending upon the direction in which they drag the probe strip. This simulates the operation of a scanning probe microscope in which variations in force between a substrate and atom-sharp probe tip can be used to image individual atoms. For illustrating x-ray diffraction, optical transform slides are used to view a point source of light (a red LED). The 35-mm slides contain eight laser-written, photographically reduced arrays that simulate different atomic packing arrangements. Among the arrays are ones that illustrate how the structures of DNA and Nitinol were determined.

LED Module

The third module is based upon the light emitting diode (LED), which is revolutionizing many industries, including those related to lighting, displays, and CD-ROM technologies. This module leads students through a series of investigations that illustrate the differences between metals, semiconductors, and insulators. The interrelationships of light, crystal structures, and chemical composition are also addressed in this module by examining properties of LEDs. Students have an opportunity to use the periodic table as a design tool in identifying an appropriate chemical composition to provide a desired color of light.

Assessment

The first two modules were field tested and implemented at James Madison Memorial High School during the fall of 2000; the third was used in January, 2001. Informal student interviews indicated enthusiasm for the modules and students performed well on the examinations that had been prepared to accompany the modules. Moreover, a number of students have of their own volition brought to class articles relating to use of technologies that were directly and indirectly associated with the modules. We are currently awaiting approval of a human subjects protocol that will enable us to conduct a more formal assessment of student attitudes resulting from use of the modules. Assessment of teacher response is also underway through our campus Learning through Evaluation Adaptation Dissemination (LEAD) Center[5].

Currently, the Teaching Companion is undergoing revisions based on technical feedback from MRSEC personnel and pedagogical feedback from high school science teachers. Once editing has been completed, the Teaching Companion will be disseminated both in hard copy through a publisher and via the web. Readers who are interested in obtaining a free copy are encouraged to contact the authors at ellis@chem.wisc.edu. The authors welcome constructive feedback.

Acknowledgments

We are grateful to Mark Connolly, Sue Daffinrud, and Susan Millar of the UW-Madison Learning through Evaluation Adaptation Dissemination (LEAD) Center; Eileen Callahan, Terrence Millar, and Keivan Stassun of the UW-Madison Graduate School; and the chemistry students of James Madison Memorial High School and the Madison Metropolitan School District who participated in field tests for their assistance with this project. We thank Nicola Ferrier for encouragement. This work was generously supported by the National Science Foundation through the Materials Research Science and Engineering Center for Nanostructured Materials and Interfaces (DMR-9632527 and -0079983), the Research Experiences for Teachers program (DMR-9632527 and -0079983), and GK-12/K-Through-Infinity Professional Development Partnership (9979628). The Institute for Chemical Education is thanked for providing some of the supplies used in this project.

References

[1] National Research Council. *National Science Standards*. National Academic Press 1999.
[2] UW-Madison MRSEC Exploring the Nanoworld Home Page. *http://www.mrsec.wisc.edu/edetc/nano/* (accessed March 2001).
[3] UW-Madison K-Through-Infinity Home Page. *http://www.wisc.edu/gspd/kti/kti.html* (accessed March 2001).
[4] The Institute for Chemical Education Home Page. *http://ice.chem.wisc.edu/* (accessed March 2001).
[5] The LEAD Center Home Page. *http://www.cae.wisc.edu/~lead/* (accessed March 2001).

JEREMIAH J. NEUBERT
Jeremiah Neubert is currently a master's student in Mechanical Engineering at the University of Wisconsin-Madison. He received his B.S. in Manufacturing Engineering from Saint Cloud State University in Saint Cloud, Minnesota in 2000. He is currently working as a teaching fellow with the K-Through-Infinity program at the University of Wisconsin-Madison.

CYNTHIA G. WIDSTRAND
Cynthia G. Widstrand is currently a master's student in Chemistry at the University of Wisconsin-Madison. She received her B.S. in Chemistry from the University of Wisconsin-Madison in Madison, Wisconsin in 1999. She is currently working as a teaching fellow with the K-Through-Infinity program at the UW. She participates in education and outreach events sponsored by the UW-Madison's MSREC for Nanostructured Materials and Interfaces.

ANN M. PUMPER

Ann M. Pumper received her B.S. in Mathematics and Chemistry Education from the UW in Madison, Wisconsin in 1997. She is currently working on her M.S. in Science-Education at UW and is teaching chemistry at James Madison Memorial High School, in Madison, Wisconsin. During the summer of 2000, she participated in the Research Experience for Teachers program.

C. BRUCE SWANSON

C. Bruce Swanson currently teaches at James Madison Memorial High School, in Madison, Wisconsin. He received his B.S. in Chemistry from Bradley University in Peoria, Illinois in 1965 and his M.S. in Chemistry-Education from the UW in Madison, Wisconsin. Throughout his 34-year teaching career he has taught chemistry and physics. During the summer of 2000, he participated in the Research Experience for Teachers program.

ARTHUR B. ELLIS

Arthur B. Ellis is the Meloche-Bascom Professor of Chemistry at the University of Wisconsin-Madison. His research group investigates the electro optical properties of solids, including tailoring semiconductor surfaces for use as chemical sensing platforms. He coordinates the education, outreach, and human resources effort of the UW-Madison's MRSEC for Nanostructured Materials and Interfaces (mrsec.wisc.edu/edetc).