Development and Optimization of Instruction Modules for High School Teachers on Materials Science and Engineering Education

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Abstract - An important investment for providing high-quality education to high school students as prospective scientists and engineers is the training of their teachers. One of the objectives of our Partnership for Research and Education on Materials program has been to take a very active role in the preparation of high school teachers in the area of materials science and engineering. We accomplish this by providing the teachers with a significant research experience for five weeks during each summer. Participating teachers, assisted by researchers and undergraduate and graduate students, develop a materials science related project within the context of their background as science educators. Each teacher’s project must follow established educational standards, as requested by their corresponding high schools and school district. Organizational aspects, professional development activities, and the results of this experience are presented.

Index Terms – High school education, Materials science and engineering, Instruction modules, Teachers’ training.

BACKGROUND

In April 2004, the US National Science Foundation granted the University of Puerto Rico-Mayagüez (UPRM) one of four Partnership for Research and Education on Materials (PREM) awards [1,2]. This five-year project established a link between UPRM (the leading institution) and the University of Wisconsin-Madison (UW) in order to advance the education of minority students in the area of materials science and engineering (MSE).

The project consists of two synergistic parts: a) research on nanostructured and functional materials and b) education and outreach. In order to accomplish the main goals of this endeavor, i.e. advancing minority involvement in higher education on materials, more than twenty faculty members from UPRM and UW engineering and science programs are involved. The total number of participating graduate and undergraduate students from both institutions reaches thirty.

UPRM PREM formed the Office of Education and Outreach (OEO) to coordinate all educational aspects of the project and to manage the outreach focused mainly on local public high schools. Among the key educational goals is the oversight of the establishment of a Masters of Science program in materials science at UPRM.

The OEO is also responsible for the logistics of the PREM project (organization of seminars, training of PREM students, administrative tasks, clerical assistance, etc.). In terms of outreach, the OEO supervises numerous activities intended to raise awareness among high school students of the growing opportunities in the area of MSE. All OEO activities have had and will continue to have support from all PREM faculty and students.

MATERIALS SCIENCE AWARENESS IN PUBLIC SCHOOLS

In order to broaden the impact of the project, the OEO decided to promote MSE awareness in potential UPRM engineering students. This started a multifaceted initiative that included the following activities: a) training of public school teachers in MSE issues, b) directly intervening in the public school student body through the creation of MSE clubs (led by students and supervised by trained teachers), and c) opening opportunities for science fair projects within PREM-supported laboratories.

For this to occur, the OEO received ample support from the Mayagüez School District, which facilitated an initial contact with the local public high schools. Public schools were favored due to their constant lack of appropriate funding and the possibility of broadening opportunities to low-income students was an added incentive for PREM personnel.

This paper relates the experiences of the first group of high school teachers participating in this large effort and the impact of that undertaking on MSE education at the high-school level.

TRAINING OF PUBLIC HIGH-SCHOOL TEACHERS

Before the general planning of the Teachers’ Summer Activities (TSA) program, the OEO coordinated with the Mayagüez School District Superintendent’s office to announce this opportunity to all high-school science teachers. In addition, District officers also made individual recommendations and helped to identify highly qualified teacher candidates for the TSA.

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The OEO selected a biology and a chemistry teacher from two Mayagüez public schools. Both school student bodies are very different in terms of their socio-economic backgrounds. This was also reflected in the expectations of the TSA program as expressed by both participants. While one teacher was interested in further exposing her students to the exciting possibilities of MSE (building on a strong science background), the other teacher sought to find something to motivate her students to pursue higher education.

Their corresponding levels of expertise in their areas of interest were also different. One teacher had had access to tertiary education in chemical engineering and was to some extent familiar with some aspects of MSE. The other teacher had a more formal science teacher training and was very well informed about pedagogical needs and the constraints established by the state department of education. The synergy between the teachers resulted from their different but complementary backgrounds.

I. The Role of PREM’s Partnering Institution

The UW Materials Research Science and Engineering Center (MRSEC)’s Interdisciplinary Education Group (IEG) has received national attention [3]. Since PREM’s starting date, the IEG has been providing logistical support and training to PREM’s OEO via direct interaction, email, and videoconferencing. PREM collaborated with this IEG in the Spanish translation of their educational kit about nanotechnology, titled “Exploring the Nanoworld” [4]. The new Spanish version of the kit, “Exploremos el Nanomundo,” is impacting Hispanic students by opening doors to the exciting new area of nanotechnology.

UW MRSEC administers a Research Experiences for Teachers (RET) program, funded by the National Science Foundation [5]. It provides a professional development opportunity to K-12 science teachers by pairing each teacher with a UW MRSEC faculty member or postdoctoral associate as his/her advisor on a project related to nanoscale science and engineering. This RET program has worked with middle- and high-school teachers to create educational modules relating to advanced and nanoscale materials and ad hoc characterization techniques.

This extensive expertise was made available to our PREM OEO by the partnering with the UW MRSEC IEG. The TSA program was, therefore, set up using Wisconsin’s RET program as a model. From the beginning, the OEO coordinator established a strong communication link to make the knowledge transfer as effective as possible.

II. The TSA Program

The TSA program was planned as a five-week endeavor during which the participants would be exposed to all research areas in PREM: functional composites, nanostructured magnetic materials, and superconductors processing. At the end of the first week and after learning about the available research projects, the teachers selected the research group that was to be their intellectual home for the remaining four weeks.

The specifics of each project were tailored to the background and needs of each teacher. Both participants were required to use their own research experience in PREM to create teaching modules related to MSE. At the end of the five-week program, the teachers each produced a presentation about their activities, their specific projects, and how their expectations were met.

In both research groups where the teachers were to work, ad hoc teams of three or four members were formed: the TSA participant, the leading researcher of the group (thrust area), and one or two students (graduate and/or undergraduate). In addition, the OEO ensured that both laboratories were equipped with the necessary instrumentation and tools required for each teacher’s project. The teachers met daily with their group’s lead researcher. At the end of each week, teachers provided the OEO coordinator with a progress report of their project and activities.

PREM OEO supporting personnel included a graduate student who assisted with the coordination of the TSA, including laboratory scheduling, training, etc. In addition, the UPRM Engineering Computer Center provided training in software packages such as advanced Microsoft Office™. The teachers also visited all PREM laboratories where they were exposed to the different synthesis and characterization instrumentation available. The UPRM librarians demonstrated the use of database searching software packages.

Even though the teachers focused in one research area, they learned about all aforementioned PREM thrust areas. For this purpose, all PREM investigators were asked to present a basic seminar about his or her research project to the TSA participants.

III. The Projects

The projects selected by the participants were:

- Modeling of dislocation sliding and strengthening mechanisms in metallic materials
- Synthesis and characterization of gold nanoparticles

For the first project, the supervising researcher helped the teacher to develop a basic understanding of dislocation theory and plastic deformation. The participant learned about abstract concepts related to slip systems, the role of dislocation in permanent deformation of solids, basic strengthening mechanisms, and obstacle/dislocation interactions.

However, the main challenge these concepts present is the underlying theoretical background required from a learner. If high-school students were presented with these mechanisms in trying to explain manufacturing based upon deformation, they would likely lose interest due to the dry, theoretical approach. However, students might gain a much clearer understanding of the topic if they are presented with a macro (physical) model that imitates dislocation motion.

This practical approach was done by means of a glycerin film sliding on a transparent Plexiglas™ box. The main constraints of the resulting model were portability and price. The TSA participant and an undergraduate student were in charge of the design of the model.
A proof of concept design corroborated the feasibility of the project (Figure 1). This first attempt was simple and very inexpensive: a cookie pan, glue, drinking straws, and glycerin (or any transparent liquid with high viscosity). The added value of this rudimentary model was that it could be easily reproduced by the teachers’ students.

After the third week a final design was produced, tested, refined, and optimized. It proved effective in emulating dislocation slippage on compact crystallographic planes (Figure 2). It was also successful in showing the resulting interaction between a moving dislocation and obstacles with different sizes and arranged in different patterns.

The second project on gold nanoparticles synthesis required more careful planning. The lack of any basic infrastructure in the teacher’s public school limited the portability of any instruction module developed in the lab. Therefore, an alternative was devised with the teacher’s assistance.

In this case, the teacher participated in the regular activities of the host laboratory, getting familiar with the instrumentation, synthesis capabilities, and safety standards. This helped her to learn very easily about gold nanoparticles and the synthesis methodology (Figure 3). As she acquired this knowledge, she started developing the accompanying demonstration module according, keeping in mind the budget restrictions of her school district.

An undergraduate student in that laboratory was in charge of producing Flash™ animations for the main researcher and his graduate assistants. In order to produce those animations he interacted heavily with the person behind the corresponding research to make the presentation scientifically accurate.

This onsite expertise created an ideal learning environment for the TSA participant. Under her guidance, the Flash™ expert constructed a pedagogically-thorough animation. The module was aimed at a Spanish-speaking audience and was entirely set up in Spanish. The animation was divided into background slides that started with a brief explanation of nanotechnology, nanomaterials, and their current and potential impact in society (Figure 4).

Then the animation presented the topics of gold nanoparticles synthesis, their characterization, and their applications. The module starts with a demonstration of a down scale from meter to millimeter to micrometer with representative familiar objects: ruler, fleen, DNA molecule, and an atom. Brief explanations of atom

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aggregation and crystal structures follow. Final, the actual synthesis laboratory based on H\textsubscript{3}AuCl\textsubscript{4} and trisodic citrate is explained and the use of an ultraviolet scanner to determine particle size is described.

**IV. Teamwork in Research Groups**

The one-on-one interaction between researcher and teacher and between teacher and PREM student was an unexpected and fulfilling experience for everyone involved. The beneficial interface between a university and K-12 schools could not have been more effectively demonstrated. Within PREM, students became more involved with their own research projects as they realized the direct impact the overall project was having in local society and education. Investigators were motivated to sustain these efforts to involve the youth (particularly those coming from low-income families) who otherwise would not have had access to this field of knowledge. Naturally, the TSA participants were the most affected by the experience by having access to state-of-the-art technology and concepts that can help them to construct an educational path (with enormous potential) for their own students. In summary, the level of satisfaction demonstrated by everyone involved, especially the teachers, was a manifestation of very effective teamwork.

The research groups supporting the teachers each had three to four individuals. Recent research has indicated that this group size is necessary and sufficient to perform better than the best of an equivalent number of individuals on intellective problems [6]. The outcomes of this TSA program are additional proof of that assessment of group size and the effectiveness of teamwork.

**TSA BROADER IMPACT**

The centerpieces of this five-week program were the educational modules adjusted to the pedagogical requirements mandated by the School District. These modules were also carefully designed to have two additional very important characteristics: affordability and portability. They were designed as ready-to-use instructional tools for public school classrooms.

An exit survey of TSA participants revealed their sense of fulfillment. Additional training in software packages was also much appreciated. The motivation to support other initiatives of PREM in terms of outreach was apparent. As a result of the teachers’ participation in our summer activities, the teachers encouraged their science students to explore the MSE area and nanotechnology in particular. Four high-school students initiated and completed their science fair projects with PREM research groups. In parallel, two MSE clubs were formed in both schools and are currently active in promoting MSE awareness among other students.

Our Wisconsin partner also gained from the efforts of our OEO program. The high-school MSE clubs provided a venue for testing and using the UW MRSEC’s education and outreach materials with a Spanish-speaking audience, and our UW colleagues have indicated that they plan on using some of the new, value-added activities PREM integrated into its TSA program, like the computer and software training the teachers received. The sharing of expertise has gone both ways between both institutions.

The synergy between research institution, minority institution, and public-high schools was clear from the start of the project. Language barriers were shattered. High school students were positively affected from several sides: through their teachers and directly via their direct involvement in research. University students were exposed to the impact of outreach in society. Professors created a lasting relation with high schools. In the end, new horizons were made visible to a new generation of young and motivated minds.

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