Nanotech Innovations: Nanotechnology Enterprise at Michigan Technological University

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An innovative, goal-oriented, and active-learning educational experience called the Michigan Tech Enterprise Program (http://www.enterprise.mtu.edu) was initiated a decade ago in order to provide a vehicle for undergraduate engineering students to experience the development and operation of a commercial enterprise and to actively address industry's needs for engineers with strong technical, communication, interpersonal, leadership, entrepreneurship and business skills. This highly successful program now supports 27 enterprises with over 700 students- more than 10% of the total undergraduate student enrollment at the university. Within this framework, a new nanotechnology-related enterprise called Nanotech Innovations Enterprise (NIE) was launched in January 2008, with the help of an National Science Foundation Nanotechnology Undergraduate Education in Engineering grant (Fig. 1). The mission of NIE is to engage students in a comprehensive hands-on entrepreneurial educational experience, including management, market research, technical research, product

Fig. 1. Screen shot of the Nanotech Innovations Enterprise website's front page at http://nano.mtu.edu/ni/

development, service, outreach, and education related to nanoscale science, engineering and technology (NST). The primary goals of NIE are to:

1. Integrate nanotechnology into engineering and science education at Michigan Tech via a continual core of dedicated students (the NIE members).
    a. Develop a sustainable business model, branding, and student leadership team;
    b. Develop, build and market an affordable STM system and accessories for distribution to participating high school teachers;
    c. Research, develop and market other selected nanotechnology products, tools, and services, particularly those related to sensing technologies;
    d. Significantly impact ~180 undergraduate engineering students over the first 2-years through NIE involvement, explorations, and new modules and courses;
    e. Maintain a balanced emphasis on the foundational science, exciting applications, and societal implications of NST, building on the successful nanotechnology education framework already established at Michigan Tech[2,3];
    f. Develop curricular modules and courses in
        i. scanning probe microscopy (AFM and STM),
        ii. nanotechnology commercialization,
        iii. nanotechnology business plan development,
        iv. intellectual property ethics.
2. Enhance and broaden the undergraduate educational experience of a wide variety of Michigan Tech students, including non-engineering students.
3. Contribute to the advancement of NST education, including societal implications, for up to 12 high school teachers and 500 students through workshops and on- and off-campus presentations.

These goals are in addition to the overall goals of the Michigan Tech Enterprise Program[4,5]:

1. Create an environment for students to facilitate the transition from their undergraduate program to the professional workforce;
2. Provide opportunities for students and faculty to develop leadership and entrepreneurial skills in a learning setting that closely resembles an industrial or professional environment;
3. Give the students ownership of a portion of their academic program that connects strongly to career goals;
4. Give students a taste of the rewards and accountability associated with creating new products and working with paying clients; and
5. Utilize the students' fundamental background in science and engineering in the context of a problem when non-technical issues, such as cost or societal impacts, are of equal importance.

Students choosing to participate in NIE come from a wide variety of disciplines, including non-engineering disciplines. Currently, 16 students from the following engineering programs are enrolled: biomedical engineering (6), mechanical engineering (2), electrical and computer engineering (3), and materials science and engineering (1). In addition, 3 physics majors and 2 business majors are participating. Primary participation in the enterprise is through enrollment in a 1-credit enterprise project course each semester, often starting in the student's sophomore year. Seniors, who are expected to take more leadership roles, may sign up for two credits each semester. Students may also

take 1-credit modules in enterprise-related courses such as leadership, teaming, communications, entrepreneurship, business planning, ethics in engineering design and implementation, product/process development, or technical courses such as industrial health and safety or the new course in practical scanning probe microscopy. Participation in the enterprise can count toward free electives, Senior Design projects, an Enterprise Certificate program, a university minor in Enterprise, or toward the research requirements of the university minor in Nanotechnology.

The Nanotech Innovations Enterprise is currently developing seven major projects in addition to developing structural and policy aspects of the enterprise. Structural aspects include the election of officers (President, Vice President for Public Relations, Vice President of Finance, and Vice President of Records), lab and office spaces, recruiting, web site development, etc. Draft policies, dealing with issues of election procedures, job descriptions, meetings, project documentation, and grading, were developed during the first semester of the project and are currently being refined as the team learns first-hand what may or may not work, and what issues are currently of pressing interest. Students may work on up to two projects unless they are an officer, in which case they can only participate in one project team. The enterprise meets weekly as a whole group for project updates, brief business, and a topical presentation. Topics for presentations that are planned for this semester include societal implications issues, communications and conflict resolution, technical themes, and several on business plan development. Projects each have a project manager and additional meeting times.

Several primary projects center around nanoscale science and technology education and outreach activities for high school students and teachers, as well as first- and second-year undergraduate students. All NIE members are expected to participate in education and outreach activities, especially early in their enterprise involvement. The Outreach team's primary function is to develop and coordinate these educational activities. A focal point of many of these activities is the demonstration of scanning probe microscopes, of the enterprise has an atomic force microscope (AFM) and a portable scanning tunneling microscope (STM), both of which are easyScan2 models manufactured by Nanosurf AG (Switzerland). In addition to being portable, these instruments are very robust, provide excellent usability and results, and are ideal educational purposes (Fig. 2). For first-year engineering students in the required Engineering Fundamentals class, a two-hour "exploration" introducing NST topics and providing live demonstrations of AFM, STM, scanning electron microscopy, and focused ion beam milling will be offered. Undergraduates will also gain exposure to NIE through participation in annual exhibitions such as the university's annual Enterprise Expo in which all enterprise and senior design projects exhibit their work. Outreach and educational activities for high school students are offered both on and off campus during the academic year as well as in the summer through the university's Summer Youth Programs and the annual *YES! Expo*[6] held at Ford Field in Detroit, Michigan. These activities will be further developed and expanded in cooperation with high school and middle school teachers through a series of teacher workshops being developed to introduce teachers to NST topics and to assist teachers in developing related curricular activities they can use in their classrooms.

An associated project is the development and building of a Lego® Mindstorms-based scanning probe imaging machine that is computer interfaced and that can

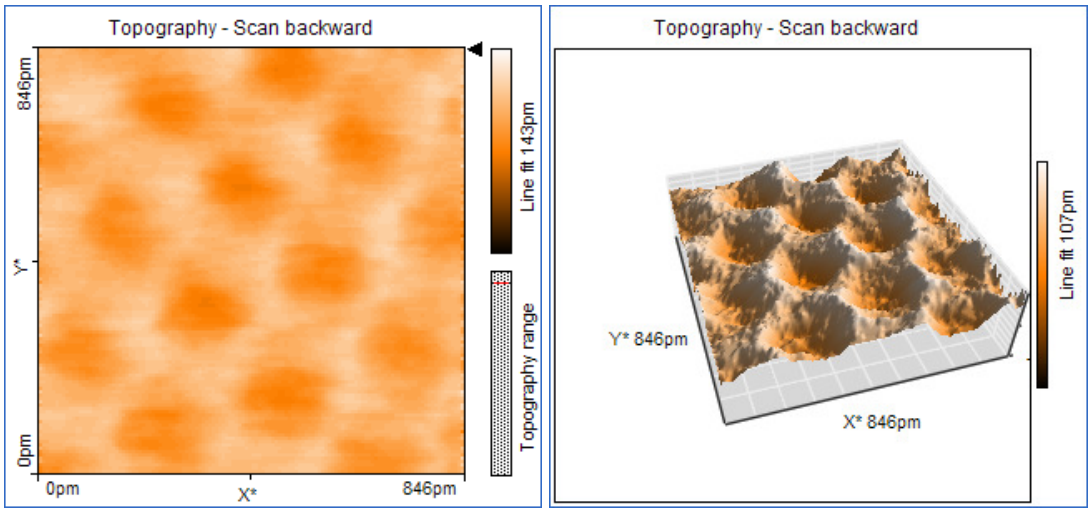

Fig. 2. Atomic-scale scanning tunneling microscope (STM) images of the surface of highly oriented pyrolitic graphite (HOPG) obtained in the Nanotech Innovations Enterprise laboratory using the Nanosurf ® easyScan2 STM (http://www.nanosurf.com).

demonstrate the fundamental principles of scanning probe microscopy but is more amenable to interactive classroom or outreach presentations. Based on a prototype design, middle school or high school students could possibly form teams to further explore, enhance and build their own designs. NST-related sample kits and supporting documentation, graphite crystals for graphene research and development, scanning tunneling microscope design and development. Perhaps the most ambitious project is the development of a simple STM that would cost under $1,000 but be sufficiently robust for use in high school laboratories. Yet another associated project team has goals of developing know how, student laboratories (high school and undergraduate), and devices to supplement and improve the operation of STMs for education.

Because of its exotic electronic and magnetic properties and its potential uses in new electronic devices, there has been tremendous recent interest in the material known as graphene[7,8]. This two-dimensional material- composed solely of sp^2-bonded carbon atoms one atomic layer thick- can be produced by mechanically separating the layers of carbon in graphite and has only recently been verified experimentally. Interest among scientists in obtaining high-quality graphite crystals for graphene research, and also for use as STM samples and AFM sample substrates, has led to a market for the sale of high-quality natural graphite crystals. NIE has established a graphite team to isolate, characterize, and market high quality natural graphite crystals through a subsidiary, Naturally Graphite, and associate web site graphitecrystals.com (Fig. 3).

Taking advantage of nanotechnology-related projects being conducted under the direction of faculty across numerous disciplines across campus, an exciting project involves the development of educational sample kits for scanning probe microscopy. Currently, a prototype kit is under development that will contain six different samples that can successfully be imaged by AFM or STM. The kit will also contain informational materials explaining how the samples can be successfully imaged, why the samples are particularly interesting, descriptions of how they are fabricated, and selected references for further reading. A supplemental CD will contain animations giving further illustration

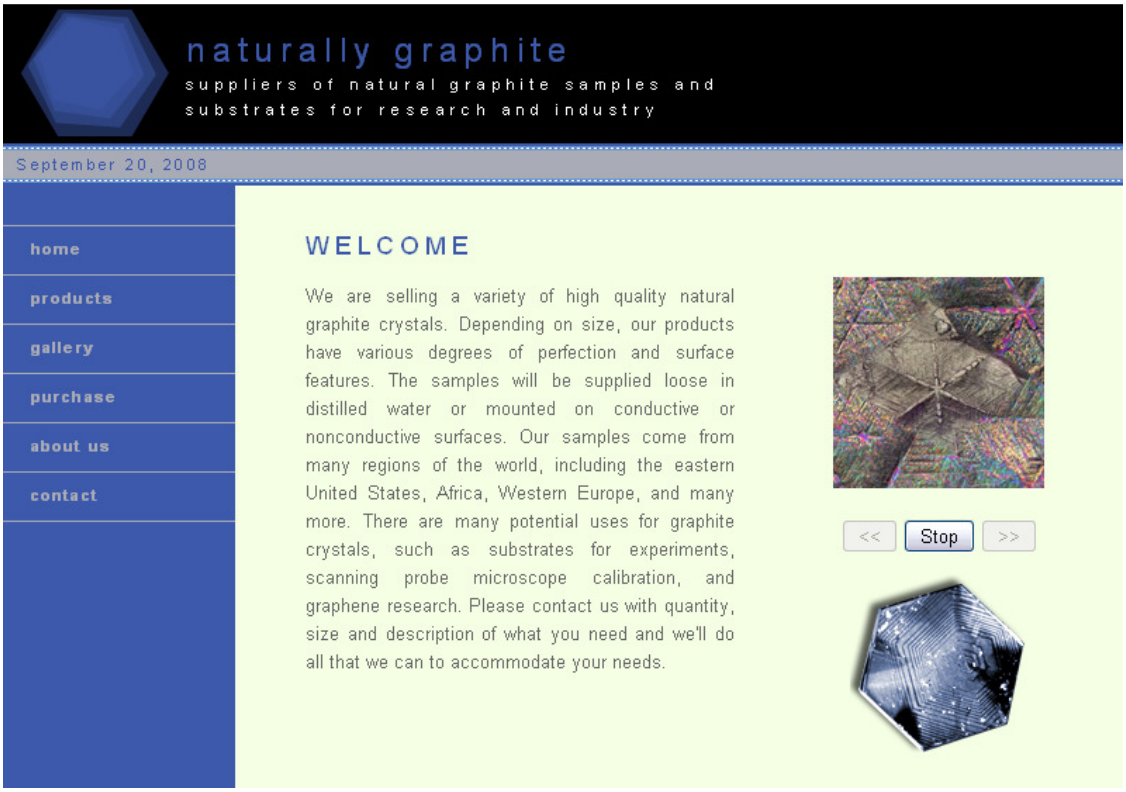

Fig. 3. Screen shot of the *Naturally Graphite* web page at http://graphitecrystals.com, advertising high quality graphite crystals for research and industry. Crystals are most commonly sought for scanning probe microscopy applications or for the fabrication of graphene.

of the applications and fabrication of the sample in the kit. It is anticipated that the first prototype kit will contain samples of:

1. Natural graphite crystal with growth spirals (relevant to materials science, mineralogy, and geology);
2. Carbon nanotubes grown by chemical vapor deposition;
3. Photonic crystal devices;
4. Single electron transistor device;
5. Microporous silicon;
6. Collagen fibers for nerve regeneration research

The enterprise also plans to develop self-contained laboratory guides for use in high school or advanced undergraduate laboratories appropriate to each type of sample.

Interest in the nanotechnology enterprise by students has been very gratifying. Enrollment started with 10 students in the first semester and has grown to 12 students in the summer, and 16 now in its second academic semester. Inquiries by interested students are also continuing as current NTE members work to recruit new members. Starting a new enterprise has been both rewarding and challenging. Perhaps the most challenging issue from the standpoint of advising is learning to appropriately balance the degree of direct involvement with both projects and structural issues of the enterprise. Another challenge faced was the development of policies and procedures while at the same time all participants were just learning about the enterprise program and the nanotechnology-related projects. As might be expected, the enterprise has experienced firsthand some

conflicts and communication shortcomings, which have served to emphasize the importance of these issues in developing new collaborative teams. On the other hand, it is very gratifying to see students from diverse backgrounds, majors, and personalities working together and so quickly realizing many of the goals of the enterprise. All necessary teams are formed, project goals have been identified and progress documented, and the Nanotech Innovations Enterprise web sites are now public. The first of the teacher workshops is scheduled for February 2009 and already there is more interest among teachers than we are likely to be able to accommodate. The graphite project team has also launched its website, begun marketing its products, and has already made several sales. The goal-oriented nature of the enterprise, the intrinsic "student ownership" of the enterprise, and the focus on an exciting emergent technology are highly engaging for the students. We are excited to see students learning here the skills that will help them to continue to "create the future" when they leave Michigan Tech.

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