## NSF Highlights

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# Interactive Nano-Visualization of Materials over the Internet

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### Background

It is generally accepted that active visualization-based learning can heighten understanding and retention (*1*). Although technology infusion in education has greatly aided the educator in delivering knowledge, technology is still primarily relied upon in traditional ways, such as word processing, and as a presentation tool. However, by employing a direct visual approach to learning, the Interactive Nano-Visualization in Science and Engineering Education (IN-VSEE) project endeavors to remove many of the conventional barriers that hinder effective teaching and learning by empowering learners with Internet access to revolutionary scanning probe microscopes (SPMs) that can image materials at resolutions down to the atomic scale (*2–4*).

One of the primary motivations for the project is the need for educating the next generation of students in the emerging fields of nanoscience and nanotechnology. In particular, advances in science and technology have led to the design and manufacture of materials and devices of increasingly smaller dimensions that surpass the resolution capabilities of the unaided eye. Since the 1960s, device sizes have decreased from millimeter to micrometer and now are approaching the nanometer scale. Scientists and engineers are working to develop technologies to construct devices starting from smaller and smaller components. Such nanotechnology may well become a manufacturing reality in the next decade, and indeed may lead to the next industrial revolution.

### Project Description

The objective of IN-VSEE is to integrate nanoscience and nanotechnology concepts into upper-division high school and lower-division college curricula. To achieve this goal, IN-VSEE has developed a new educational paradigm to help students understand the structures and properties of matter on the nanoscale. This project uses the Internet to help a consortium of university and industry scientists, community college and high school faculty, and museum educators to realize common educational goals via an interactive Web site. IN-VSEE has successfully exploited the Internet as a rich resource tool to achieve a number of asynchronous learning objectives. These objectives include the ability to (i) provide a highly interactive learning environment that promotes discovery and active learning, (ii) empower students with ownership of the images they create while exposing them to the excitement of working at one of the frontiers of science, (iii) locate and download images for analysis and as a tool for students to contribute their data to the scientific community, and (iv) allow teachers and students to interact with their counterparts at other institutions as well as to collaborate with research scientists at universities and in industry.

IN-VSEE is currently developing three major resources: novel remote experiments, interactive educational modules on a broad spectrum of materials, and a diverse image gallery. Through IN-VSEE's Web site at *http://invsee.asu.edu*, educators and students can find detailed information about each of these resources. Only a brief description is given below.

IN-VSEE has developed SPM Live!, the first interface for remote operation of SPMs over the Internet. The feasibility of using the Internet for remote operation of research-grade instrumentation that can be used directly in the classroom or laboratory for carrying out real-time experiments has been demonstrated. SPM Live! helps convey the excitement of nanoscience and nanotechnology, promote student-initiated learning, and increase interest in science and engineering careers. IN-VSEE also uses SPM Live! to provide teachers with an introduction to the technology and its use in teaching. IN-VSEE has created a live two-way communication from a Web browser to the SPM through a remote architecture for remote control. This involves sending live data from the SPM to a remote user via the Internet and then providing a way for the user to send commands to the microscope. Although only one user can control the microscope at a time during a remote session, multiple users can view and analyze the data simultaneously and control can be passed from one user to another (Fig. 1).

The educational modules provide interactive, discovery-based learning activities to introduce students to the SPM as

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a research instrument and to interpret the data collected. For example, students can view a video of a process and then answer questions about what they have observed. They can also explore a concept they have experienced in a module or discussed in class, or they can discover the concept on their own using Java applet-based activities. Each module presents important fundamental and applied concepts of natural and manmade materials that cut across the traditional disciplines of mathematics, physics, engineering, chemistry, and biology. The modules demonstrate how a material's atomic structure, properties, processing, and performance are related at the nano level and how that relationship leads to its properties and performance at the macro level. This visualization pipeline provides examples of manmade and natural materials ranging from the macroscopic to the nanometer scale. One aim of the modules is to provide an effective bridge between the classroom and the laboratory. Each module has the ultimate goal of drawing the student into the use of the SPM as a data-collection tool and providing an understanding of the appropriate use of this tool. Collectively, the modules provide a road map for students on how to design and conduct experiments, with each module leading to a remote experience.

An extensive image gallery has also been created to serve as a materials visualization resource that can be used for a variety of educational purposes, including classroom presentations, homework, special projects, and honors credit. The IN-VSEE image gallery contains a unique bank of images that illustrate the interdisciplinary nature of modern science and engineering and the value of integrating research into education. The images represent a diverse cross-section of disciplines and span a wide range of size and scale. Images of various materials are provided in several forms: digital photographs showing objects from the macroscopic world, schematics that illustrate the essence of a concept being taught, animations to stimulate the student's imagination, and micrographs obtained from SPMs as well as from electron and optical microscopes. Text segments that accompany each image describe the material and the unique features displayed in the image.

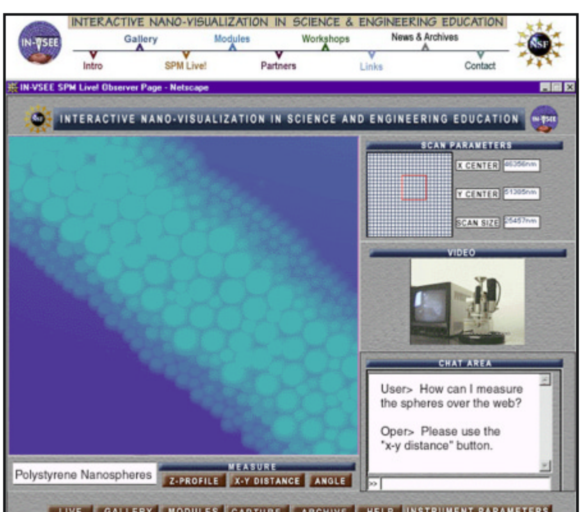


Figure 1. This remote observer Web page shows a real-time image of an aqueous dispersion of polystyrene nanospheres having diameters in a 1:2 ratio, which illustrates basic packing principles for non-identical spheres. Also shown on the right are the scanned area of the sample (top), a webcam video broadcast inside the laboratory (middle), and a chat area for user communication (bottom). Remote observers can perform image analysis online, capture images for analysis offline, collaborate with the remote operator as well as other remote observers, and become the remote operator by obtaining the remote-operator password.

In summary, IN-VSEE is piloting a new educational paradigm that utilizes cutting-edge research tools as learning tools. A unique Web-deliverable distance-learning technology, SPM-Live!, empowers the learner with live remote control of a Nobel Prize–winning microscopy technique. Remote experiments are supported by interactive, multidisciplinary education modules that explore key fundamental and applied concepts of natural and manmade materials. Each module utilizes the latest technologies, such as Java applets, streaming video and animations, live chat, and image analysis software to engage students. A diverse image gallery has also been created to serve as a materials visualization resource. The IN-VSEE educational materials developed to date not only engage students in the process of scientific investigation and the exciting fields of nanoscience and nanotechnology, but also demonstrate the potential of integrating technology in novel ways to enhance classroom learning.

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