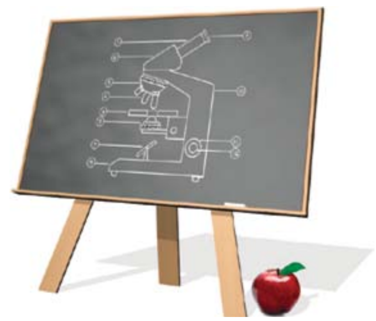
Microscopy**Education**

# Exploring Nanoscience and Scanning Electron Microscopy in K–12 Classrooms



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## Introduction

There has been a recent push to develop new active learning materials to educate students at all levels about nanoscience and nanotechnology [1]. An understanding of the structure and morphology of materials or an object at the microscale and nanoscale is fundamental to an understanding of the underlying science. These microscopies, however, often require a large investment of space, time, and money to purchase and maintain. Some high schools have received donations from grants or corporations for electron microscopes of their own [2], whereas other schools collaborate with local universities for access to university equipment [3]. But most schools do not have the resources necessary to have them on site. To address this need, many projects, such as Bugscope [4], Project ExCEL [5], or nanoManipulator [6] allowed K–12 students remote access to advanced, nanoscale microscopies such as scanning probe microscopy or scanning electron microscopy (SEM). Other outreach efforts, such as Project MICRO [7] and the Biobus [8], bring optical microscopy directly to the students. Prior to 2007, however, SEM was not a portable technology. In 2007, the first portable, table-top SEM specifically designed for science education, FEI's Phenom-Ed, was placed on the market [9]. Now, several companies market a lower-cost, user-friendly, and lighter-weight SEM including Hitachi, FEI, and JEOL, among others.

Even while new tools are developed, there are questions among teachers about how to use them in their classrooms. All too often, students learn about these new technologies in places other than their science class because teachers are unsure about how to incorporate them in their students' learning [10]. Teachers are busy, and paced standardized curricula can discourage the use of advanced technologies such as SEM in classrooms. Teachers also need help in understanding how and why SEMs are used. Schönborn and Anderson suggested that due to a lack of funding or other resource restraints, teachers must often utilize a didactic approach in their classes, using outdated materials that may be inadequate in nature. The result is that students are often engaged in a passive or receptive role in the science classroom [11]. Indeed, although these new portable SEMs are lower-cost, they are still quite expensive for a resource-poor public school classroom, with many models priced at roughly $100,000. However, the presence of technology can enhance learning environments and increase opportunities for authentic hands-on experiences [12].

To address the need for access and for teacher training in this new technology, several programs have begun across the country. Hitachi High Technologies America, Inc. (HHTA), established an outreach program that loans a tabletop SEM, their TM3000, to an educator for 1–2 weeks at a time. HHTA transports and installs the microscopes in the schools and hosts a website where teachers request the microscopes, along with nanoscience learning materials and lesson plans [13]. Their microscopes have now visited over 100 schools and colleges in California, Maryland, and Pennsylvania, among others. Another notable example is Project NANO, a program based in Portland, Oregon, that also loans tabletop SEMs to area teachers for use in their classrooms for several weeks after they receive training in nanotechnology and nanoscience pedagogy via a required course held at Oregon State University. Evaluation of these programs are ongoing, but positive results in student performance and engagement have been reported [14].

## The Mobile Nanoscience Laboratory

To broaden access to this technology to the more rural and economically challenged region of western North Carolina, Appalachian State University (ASU) and Discovery Place, Inc., a family-friendly science museum in Charlotte, NC, have partnered to establish the Mobile Nanoscience

**Figure 1:** A middle-school student using the Hitachi TM3000.

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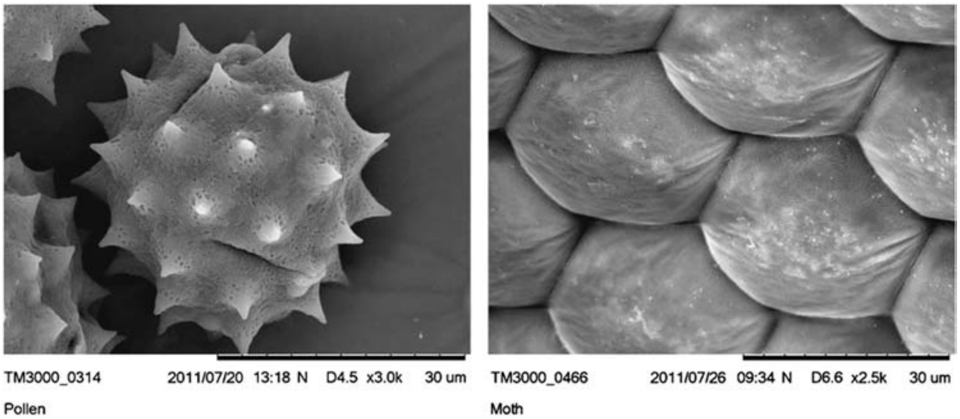


**Figure 2:** These images of daisy pollen at 3,000× magnification (left) and a moth eye at 2,500× magnification (right) were acquired by students on ASU's Hitachi TM3000 SEM.

Laboratory. ASU's College of Arts and Sciences purchased a Hitachi TM3000 portable SEM in spring of 2011. We, that is, ASU and Discovery Place, received NC Space Grant funding starting in October 2012 to establish a visiting scientist nanoscience outreach program that brings SEM directly to the hands of K–12 students and the general public. Our project goals were to increase pre-college student interest and excitement in science, technology, engineering, and mathematics (STEM) fields in order to enhance student understanding of key STEM concepts covered in the curriculum, which in turn increases student familiarity with advanced technologies in schools of Western NC in economically distressed areas. ASU provided access to the TM3000 and training in its operation to Discovery Place staff. Discovery Place greatly broadened the outreach effort and provided internships to ASU students. The student interns assisted in outreach to public schools and also brought the microscope to exhibits on the museum floor. For example, Discovery Place featured the microscope for their "Nanodays" celebrations in spring of 2013, a week when the museum had approximately 8,400 visitors.

The vast majority of the schools visited by this program are in counties that are rather far from large population centers with easy access to advanced technologies. Students in rural schools often have less access to advanced placement courses in STEM. A smaller percentage of students in rural schools go on to college after graduation. They attend schools that are located in economically distressed areas, and these schools often have more difficulty recruiting new teachers due to their location and lower average pay rates [15]. This outreach program serves the western NC counties with average per capita incomes $4,000 lower than the NC state per capita income and roughly $6,000 lower than the national average. Eight of the counties served have per capita incomes of less than $20,000 [16].

**Figure 3:** A Discovery Place staffer demonstrating the SEM to public school students.

The TM3000 has a maximum magnification of 30,000×, operates on a touch screen computer for ease of use, and is relatively compact (Figure 1). ASU students and faculty have taken the Hitachi TM-3000 to over a dozen different schools and other outreach sites over the last year and a half. Before visiting classrooms, the teachers were asked what learning materials and samples they would like to examine in the SEM to connect the event to recent studies. A wide variety of samples have been prepared (Figure 2.) Teachers could request planned activities, which were also developed to supplement student learning in key areas. Rotating smaller groups of students through multiple learning stations maximized their interest and engagement. The primary station was always the supervised use of the tabletop SEM to look at samples requested by the teacher on the microscale to the nanoscale (Figure 3). Depending on the size of the group and the access to power and internet at the site, other stations included accessing online activities that aid in understanding length scales, such as "The Scale of the Universe" [17]. Several optical microscopes of varying magnification were used at a separate station where students examined cells, insects, feathers, fibers, and minerals. The optical microscopes have a much lower magnification than the SEM, demonstrating what it is possible to view at different length scales. Several physics demonstrations that illustrate principles such as the bending of electron paths by magnetic fields were also shown at some visits to explain how the SEM works. Finally, one station included information in hard copy and/or online about STEM careers [18].

Discovery Place Educators brought the Hitachi TM3000 to workshops with their partner schools, after-school programs, and as part of the Spring Break Nano Camp and other STEM camps held at Discovery Place, often with a representative from ASU. During these hour-long sessions, students were first presented with background information on SEM and how it allows one to see smaller-length scales than traditional light microscopy. They began by choosing the objects they wanted to study using magnifying glasses, handheld microscopes, and light microscopes. They then discussed each tool's advantages and disadvantages, and when it would be appropriate to use each tool. As the culminating experience, they were given the opportunity to place prepared samples into the SEM and to look at some objects at a higher magnification. The samples included gold-coated moths, bees, pollen, and more.

## Project Evaluation

The public school teachers were asked to share their opinion of the use of and success with the new learning materials and projects provided to their students in an open-ended questionnaire emailed to them after the activity. This feedback was used to modify the learning materials appropriately. There were many responses, such as this one from John Davis at William Lenoir Middle School teacher: "My students were intrigued by the electron microscope and talked about the experience for days afterward. It gave them an opportunity to look into the world of science not normally afforded to students at their age or in my community. I have heard nothing but positive reactions to Dr. Coffey's visit and have even been asked by numerous staff members when she can come to their classrooms." Jamie Ward from Hardin Park School also responded: "The students really enjoy all of the activities. It allows them to think about estimating and exact measurements in a different ways. … Dr. Coffey works well with my middle school students to help them understand the objectives that she has in mind.... A large number of my students cannot afford to pay for field trips. By Dr. Coffey coming to my school, it allows students to have an opportunity that they would not have otherwise. My students are always disappointed that our class has come to an end and ask when she can come back."

Gains in students' science content knowledge and excitement about STEM were assessed with a pre- and post-test that was designed to match the content of the instructional modules by ASU faculty and Discovery Place Educators. Students were asked to rank their enjoyment of the activity and interest/excitement in STEM fields using a multiple-choice Likert-type scale. Results from ASU's assessment tests have been analyzed for 125 students from 6 different classrooms. One of these questions was to rank their agreement with the statement "I'm thinking of choosing science as a career." For this question, 44% of students surveyed agreed or strongly agreed with this statement after the activity, compared to 29% before the activity. Of students surveyed, 92% agreed or strongly agreed with the statement "I enjoyed today's activity and found it interesting." Results from STEM content assessment show that correct answers on the question "How does the eye see an object using light?" rose from 75% to 93% of students from before to after the activity. Correct answers on the question "How does the SEM make images of objects using electrons?" rose from 53% to 63% of students surveyed after the activity.

Discovery Place Educators added the question, "Which of the following objects can only be seen using an SEM?" to their multiple-choice content assessment. They also added the question, "Do you feel comfortable explaining to a friend what a scanning electron microscope is?" to their attitude assessment. They administered the same test to 139 different students before and after the activity and assessed the gains in content and attitude separately. They saw gains of 21% on post-test scores versus pre-test scores in both the content and attitude sections of the test.

Studies that assess the impact of scientist-in-the classroom visits are limited in the literature. Laursen et al. showed qualitatively that scientist-in-the-classroom programs can have a positive impact on students' interest in science and thus their eagerness to learn it [19]. In this study, we showed a positive impact on students' attitude and content knowledge using both qualitative and quantitative instruments, while giving students access to the SEM. However, much of the assessment was done during the approximately hour-long program. A longitudinal study that measures the sustained impact of these experiences would be necessary to confirm that these attitudinal and achievement gains remain over time. As the need grows to inspire more of our students to consider STEM fields as career options, it's important to recognize that access to these technologies may be the inspiration that is required.

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