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https://doi.org/10.1017/S1551929500061988 Published online by Cambridge University Press

Table Top SEM Utilization in a High School Nanotechnology Course

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Nanotechnology Course Description

A Duke University Talent Identification Program (TIP) [1] nanotechnology course curriculum integrated a Hitachi TM-1000 table top scanning electron microscope (SEM) into the classroom to excite and educate gifted and talented high school students interested in this emerging field of research. Students learned about synthesis, characterization and applications of nanotechnologies to encourage them to begin thinking about why and how properties of matter change at the nanoscale. The syllabus [2] was created to introduce fundamental concepts like introductory quantum mechanics, atomic bonding, allotropes of carbon and applications including nanomedicine, nanoelectronics, nano-textiles, bionanotechnology and nanometals. The classroom environment allowed students to take intellectual risks and the course content was presented through a variety of methods to utilize the Kolb learning model [3] and encompass intellectual, personal, social and practical learning methods [4]. The teaching approaches employed traditional principle based lectures, but also included guest speakers, experiential learning activities and both project or problem based learning laboratories [5,6]. The course totaled 105 hours of academic time, progressed at a rapid pace over a three week term and allowed students to utilize resources and be taught by nanotechnology researchers from four major North Carolina universities. It succeeded in teaching students a sense of scale, within the first few days of the term, through the utilization of a table top SEM and nanoscale science activities [7].

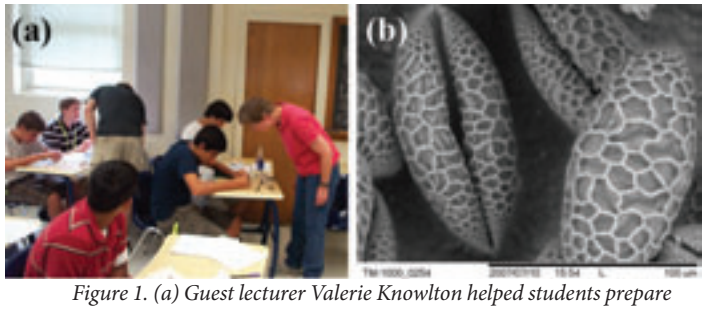

Figure 1. (a) Guest lecturer Valerie Knowlton helped students prepare pollen for SEM analysis. (b) Students imaged the pollen samples with the table top SEM.

Experiential Learning

The table top SEM gave students (1) an opportunity to view the micro-scale with nanometer resolution and (2) ownership of acquiring new knowledge by choosing their own samples to image. Guest lecturer Valerie Knowlton [8] presented fundamental SEM concepts to the class and instructed students how to properly prepare pollen samples for imaging (Figures 1(a) and (b)). The pollen samples were then loaded into the SEM, the software user interface projected (with a LCD projector) onto a large screen at the front of the classroom (Figures 2 (a) and (b)) and the entire class became familiar with the simple operation of the TM-1000. Micrographs were acquired after collective student input was in agreement about correct focus, brightness and contrast of the images. The class also actively participated in matching the size and morphology of the different pollens with over 50 micrographs of different pollen types provided to them as contact sheets.

Further understanding of the scale of things was accomplished by allowing individual students to schedule two half hour sessions on the TM-1000 in addition to showing the Powers of Ten DVD [9] to the class. During the SEM sessions, students were required to capture a series of micrographs at 50x, 500x and 5000x to appreciate the details at each order of magnitude (Figure 2(c)). The first half hour session included four pre-loaded samples (salt and pepper, a spider, microelectronics chip and the inside of an eggshell). The second half hour students chose their own samples and again acquired a series of micrographs at the same magnification range. Samples for SEM analysis chosen by students, pictured in micrographs of Figures 3(a)-(i), included a coffee bean, lint ball, broccoli, dining hall mystery fish, a nail clipping, peach skin, pine cone, pencil eraser, nail polish, Gatorade mix, a peanut, and beef jerky. After the second SEM session was completed the students created Power Point presentations with a single macroscopic digital image of their sample and also the 50x, 500x and 5000x micrographs. In a summary slide, students described the morphologies of their samples and included quantitative measurements determined from the micrograph's scale bars. The resulting student SEM presentations and over 400 micrographs acquired by them can be viewed online by visiting the Duke TIP Nanotechnology course web page [2].

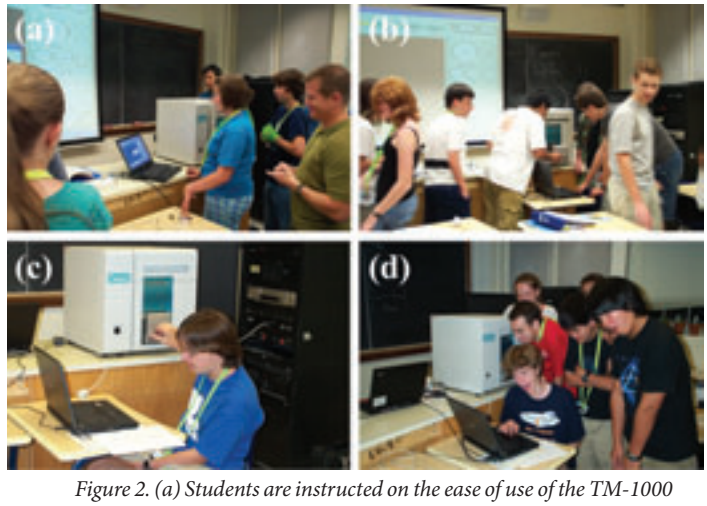

Figure 2. (a) Students are instructed on the ease of use of the TM-1000 by Mike Boykin. (b) The table top SEM was interfaced with the LCD projector so all students could observe the user interface and what was being imaged. (c) Students had one hour total individual time with the table top SEM. (d) The SEM was also used by additional TIP students during the evening social activities.

Project Based Learning

The table top SEM was not used for experiential learning only as described above, but also in a project-based learning activity involving student synthesis of Au nanoparticles, characterization with UV-vis photospectrometery (UV-vis) followed by transmission electron microscopy (TEM) and subsequent testing of the nanometals as chemical sensors. Students were divided into lab groups and synthesized wine red solutions containing ~13nm diameter Au nanoparticles [10] in the chemistry teaching laboratories located in the French Science building on Duke's West Campus. Students then took a field trip to North Carolina State University's Atomic Resolution Electron Microscopy Center (AREMC) where they learned about and operated a JEOL 2010F TEM, confirmed the nanoparticles they synthesized were ~13nm in diameter (Figures

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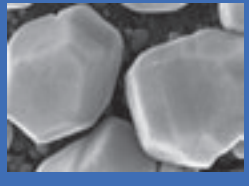

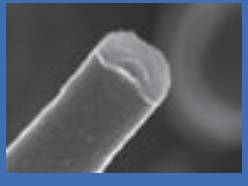

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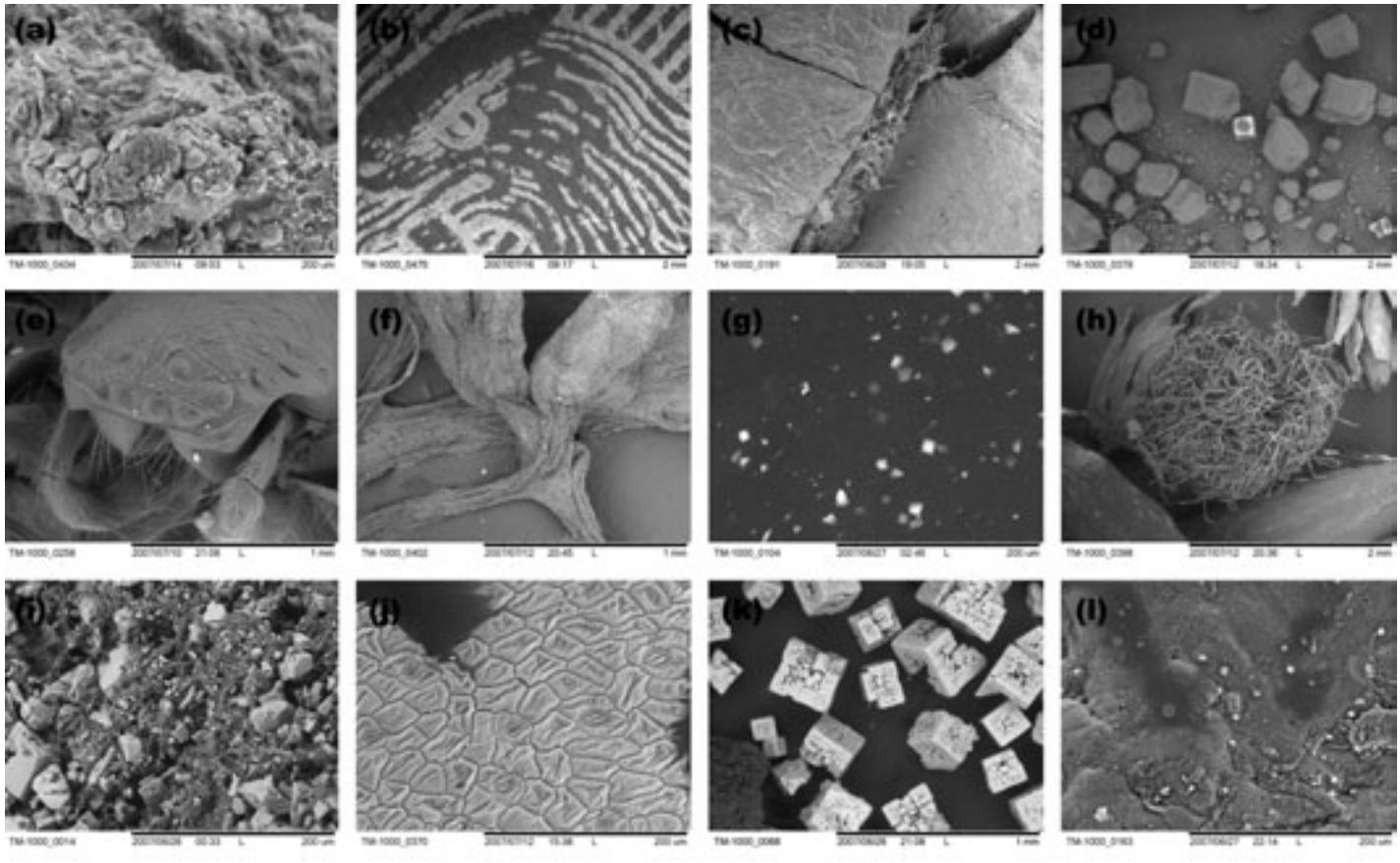

Figure 3. Student micrographs acquired with the TM-1000 table top SEM. (a) Dining hall mystery fish. (b) Eagle's eye on a dollar bill. (c) Coffee bean. (d) Gatorade drink mix. (e) A spider's eyes. (f) Cooked broccoli. (g) Nail polish. (h) Lint ball. (i) Pencil eraser. (j) Peanut. (k) Salt crystals. (l) Beef jerky.

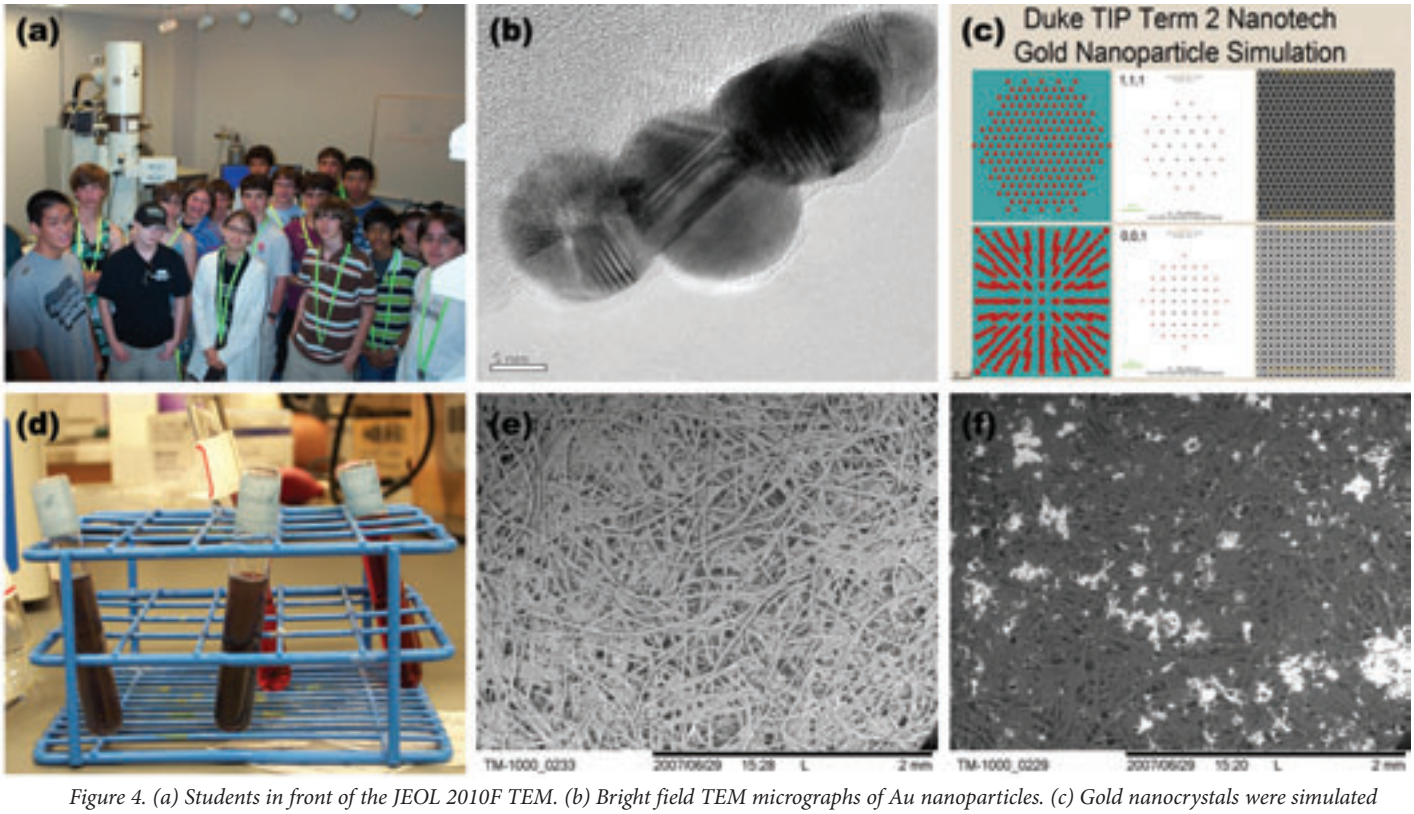

Figure 4. (a) Students in front of the JEOL 2010F TEM. (b) Bright field TEM micrographs of Au nanoparticles. (c) Gold nanocrystals were simulated with software. (d) Gold nanoparticles used as chemical selective sensors. (e) SEM images of red gold nanoparticle solution, not visible at this magnification. (f) Agglomerates of gold in the grey nanoparticle solution were observed with the SEM.

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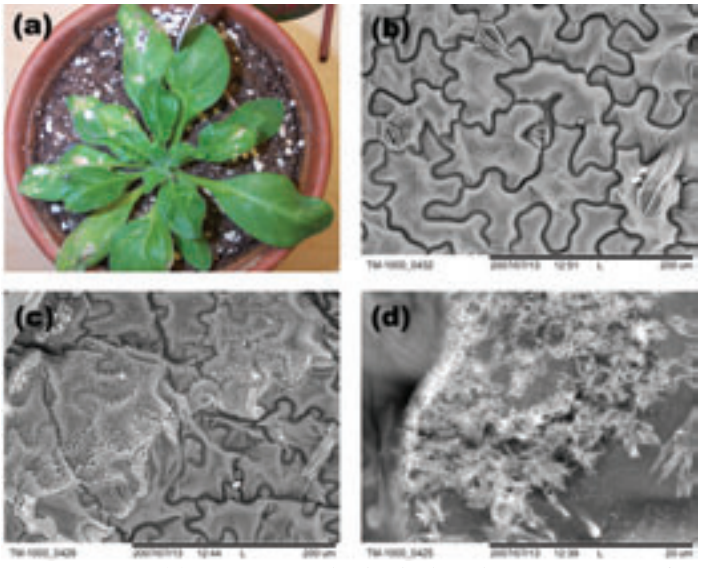

Figure 5. (a) A Nicotiana Clevelandi plant showing symptoms of RCNMV. (b) SEM micrograph of healthy leaf region of leaf from (a). (c) Changes in leaf cells in symptomatic region of leaf from (a). (d) Higher magnification of RCNMV infected region of (c).

4(a) and (b)) and for the first time observed atomic columns in a material. Students also used simulation software at AREMC to visualize how atoms are periodically arranged in nanocrystals (Figure 4(c)).

Following the nanometal synthesis and structural analysis excersises, students used the wine red colloidal Au solutions in a chemical sensor experiment by adding either NaCl or sucrose solutions to the stock solution. A visual change in color of the Au nanoparticle solution, from wine red to grey, was observed only in the solution that NaCl was added to (Figure 4(d)). Students were asked to note the experimental observations during the chemical sensor experiment, followed by making abstract conceptualizations of why this color change may have occurred. Both the wine red and grey Au nanoparticle solutions were then analyzed using a UV-vis photospectrometer and the shifts in the adsorption bands corresponding to each solution were recorded. Students then deposited 10ml of each solution on filter paper and let the samples dry overnight for future SEM observation to relate possible physical changes to the nanoparticles that may have caused the optical properties of the solution to change.

The combined low-pressure mode and backscattered electron detection of the TM-1000 enabled students to image the filter paper samples and observe Au nanoparticle agglomerates (Figure 4(f)) present in the solution that turned grey when NaCl was added to it. Shielding of the negatively charged citrate ions covering the Au nanoparticles in the wine red solution, caused by the positive Na ions introduced into the solution caused agglomeration of Au nanoparticles. The color change, shift in absorption bands and differences in morphology of the nanometals revealed by the table top SEM demonstrated to the students the cause and effect of nanoparticles used as chemical sensors.

A second project based laboratory activity presented nanomedicine and virions as biomolecular nanomachines. Visiting lecturer, Dr. Dick Guenther, presented current research involving virions of red clover necroctic mosaic virus (RCNMV) used as drug delivery vehicles for cancer treatment [11]. After the lecture, students participated in a laboratory experiment designed to teach them about how virions affect the immune systems of young and old plants. Students inoculated Nicotiana Clevelandi host plants with the virion and over the three weeks of the course noted observations about the resistance to or symptomatic progression of the RCNMV. The laboratory was designed to be run over the entire three week term and taught students patience and the observation skills needed to become successful researchers. The table top SEM was again employed by students to observe healthy versus infected plant cells as is shown in Figure 5.

Problem Based Learning

Lastly, the students employed the table top SEM to gather data on what (if any) nano-scale features caused the "lotus effect" (hydrophobicity of a material) exhibited by peach skin, plant leaves and nanoTex fabric. Students worked in 2-3 person lab groups and tested the response of liquids such as orange juice, water, creamer and coffee when added drop-wise to the surfaces of all three samples. Students were surprised by the similar macroscopic behavior of the liquids and amazed that the nanoTex fabric would not absorb any of the fluids it came in contact with. The results of the "NanoTex vs. Coffee" experiment were captured as digital video and posted online as a YouTube video [12]. Students used the TM-1000 SEM to gain a microscopic and nanoscale understanding of biomimicry and determined what was responsible for the "lotus effect" exhibited by the samples tested. Figure 6 includes the resulting micrographs from the surfaces of the peach skin, plant leaf and nanoTex fabric. It was observed that the peach skin contained small spikes (peach fuzz) on the surface which did not rupture the water droplets resulting in the hydrophobic surface. Students also discovered the mechanisms responsible for similar hydrophobic behavior of the plant leaf and nanoTex fabric were more subtle and were asked to

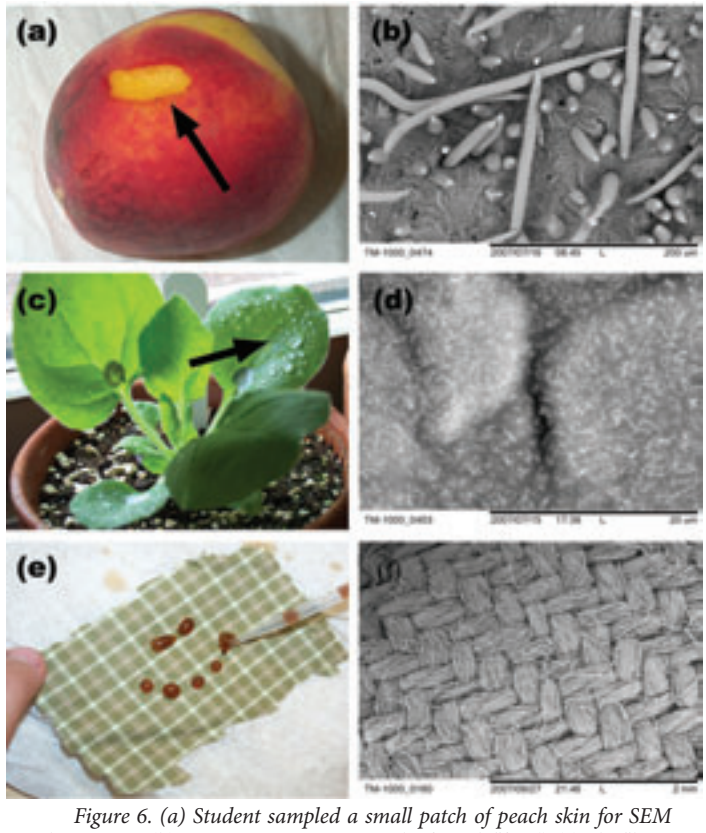

Figure 6. (a) Student sampled a small patch of peach skin for SEM observation. (b) Low mag SEM micrograph of peach "fuzz". (c) The "lotus effect" occurring on a plant leaf. (d) Nanoscale features on the plant leaf possibly responsible for the "lotus effect". (e) NanoTex fabric being tested by student. (f) SEM micrograph of the NanoTex fabric.

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include a hypothesis of possible mechanisms in addition to summarizing their findings in a written lab report.

Conclusions

Integration of the TM-1000 table top SEM in the high school nanotechnology course was well received by the students. It not only aided in helping students gain a sense of scale but also helped excite them about science, which created an environment where emotional based learning [13] took place. Students also completed an online inventory of learning styles questionnaire [14] and it was found that 90% of the 34 students were visual learners [15]. The table top SEM in the nanotechnology course was well suited to this type of visual learning style that most students possessed.

Acknowledgments

The course could not have been a success without the help and contributions of many individuals and organizations. I would like to thank the following people for making the summer of 2007 a memorable one for the students of Duke TIP Nanotechnology: Robert Gordon, Beth Moseley and Dr. Konrad Jarausch (Hitachi High Technologies America, Inc.), Mike Boykin and Paul DeGeorge (Marine Reef International, Inc.), Dr. Tom Rawdanowicz and Andy Newell (North Carolina State University's Atomic Resolution Electron Microscopy Center), Dr. Dale Batchelor, Chuck Mooney and Roberto Garcia (North Carolina State University's Analytical Instrumentation Facility), Wendy Salmon and Michael Chua (Michael Hooker Microscopy Facility, University of North Carolina Chapel Hill), Dr. Rich Superfine and Dr. Mike Falvo (Nanoscience Research Group,University of North Carolina Chapel Hill), Dr. Phil Russell (Dept. of Engineering Physics and Nanoscience, Appalachian State University), Valerie Knowlton and Dr. Richard Guenther (North Carolina State University) and Dr. Adam Wax (Dept. of Biomedical Engineering, Duke University) and teaching assistant Nicholas Barone. ■

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[1] Detailed information on the Duke TIP program can be found at the website: www.tip.duke.edu

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