HOW TO DO IT

Convergent Inquiry in Science & Engineering: The Use of Atomic Force Microscopy in a Biology Class

IL-SUN LEE, JUNG-HO BYEON, YONG-JU KWON

Abstract

The purpose of this study was to design a teaching method suitable for science high school students using atomic force microscopy. During their scientific inquiry procedure, high school students observed a micro-nanostructure of a biological sample, which is unobservable via an optical microscope. The developed teaching method enhanced students' science-learning motivation and scientific creativity.

Key Words: *AFM; teaching biology; scientific inquiry; science and engineering; biomimetic inquiry.*

Nanotechnology is an up-to-date technology that accelerates the creation of diverse and valuable knowledge. Current research in nanotechnology is centered on technological applications of biology, such as biomimicry (Benyus, 2002). Biomimicry, or biomimetic analysis, is a method of problem solving and design based on the structures and processes of life. Examples include the development of new architecture, instruments, and systems through observation of living organisms.

According to Ekli and Şahin (2010), the introduction of content and studies related to biomimicry can trigger interest and motivate students to learn about science. In other words, when students – in particular, those who reveal remarkable talent in science and who dream of one day becoming scientists or engineers – are given opportunities to experience biomimetic and bio-nanotechnology activities first hand, they will not only have more interest in science, they will also be more motivated in the science classroom. However, present-day curricula seldom provide opportunities for students to experience such inquiry activities, owing to a lack of suitable high-resolution imaging systems like TEM, SEM, and AFM.

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Atomic force microscopy (AFM) could present a new alternative for overcoming the absence of biomimetic inquiry experiences in the science class. Because of its high spatial resolution, AFM can identify the micro-nanostructures of a biological sample. Moreover, observation of micro-nanostructures using AFM is simple and easy, and smaller mobile-type AFM equipment is suitable for use on a school desk. These advantages make it a useful apparatus for science students during inquiry activities. Here, we introduce a sample lesson for biological inquiry that focuses on micro-nanostructures using AFM. The lesson is designed for use in biology classes at the secondary and postsecondary levels. This is a more effective and appealing activity than the typical optical- and electron-microscope activities used in science classes, and AFM closes the gap between science and engineering.

○ What Is AFM?

Atomic force microscopy is used in material technology to solve a wide range of problems related to electronics, telecommunications, biology, chemistry, automobile industry, aerospace, and the energy industries. Materials analyzed with AFM include film coatings, ceramics, composites, glasses, synthetic fibers, biological membranes, metals, polymers, and semiconductors. AFM is also employed when studying phenomena such as abrasion, adhesion, cleaning, corrosion, etching, friction, lubrication, plating, and polishing. It enables one not only to image the surface in resolution at the atomic level, but also to measure force on the nano-newton scale. For more detailed information, see the rapidly increasing number of publications related to AFM, including those of Shao et al. (1996) and Morris et al. (1999).

○ Operation of AFM

The principles upon which AFM operates are very simple. An atomically sharp tip with feedback mechanisms scans a sample surface. The feedback mechanisms enable piezo-electric scanners to maintain the tip above the sample surface at either constant force to obtain height information or constant height to obtain force information.

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An AFM tip is typically made from Si3N4 or Si and extended down from the end of a cantilever. The nanoscope AFM head employs an optical detection system in which the tip is attached to the underside of a reflective cantilever. As the tip scans the surface of the sample, moving up and down with the contour of the surface, a diode laser beam detects the cantilever's movement and sends a signal to a dual element photodiode. This photodiode measures the difference in light intensities between the upper and lower photo signal and then converts this difference to voltage. Feedback received from the photodiode signal, through a computer software control, enables the tip above the sample to maintain either constant force or constant height. When set to maintain constant force, the piezo-electric transducer monitors real-time height deviation; when set to maintain constant height, the deflection force on the sample is recorded. The latter operation requires that scanning-tip calibration parameters be input into the AFM head during force calibration of the microscope (Amrein & Müller, 1999; Morris et al., 1999; Lillehei & Bottomley, 2000).

A number of AFM scanning systems can accept full 200-mm wafers. The primary purpose of these instruments is to quantitatively measure surface roughness with a nominal 5-nm lateral and 0.01-nm vertical resolution on all types of samples. Depending on its design, an AFM scanner translates the sample either under the cantilever or over the cantilever. Regardless, both scanning methods measure the local height of the sample. Three-dimensional topographic maps of the surface are then constructed by AFM software by plotting local sample height and horizontal probe-tip positions (Amrein & Müller, 1999; Figure 1).

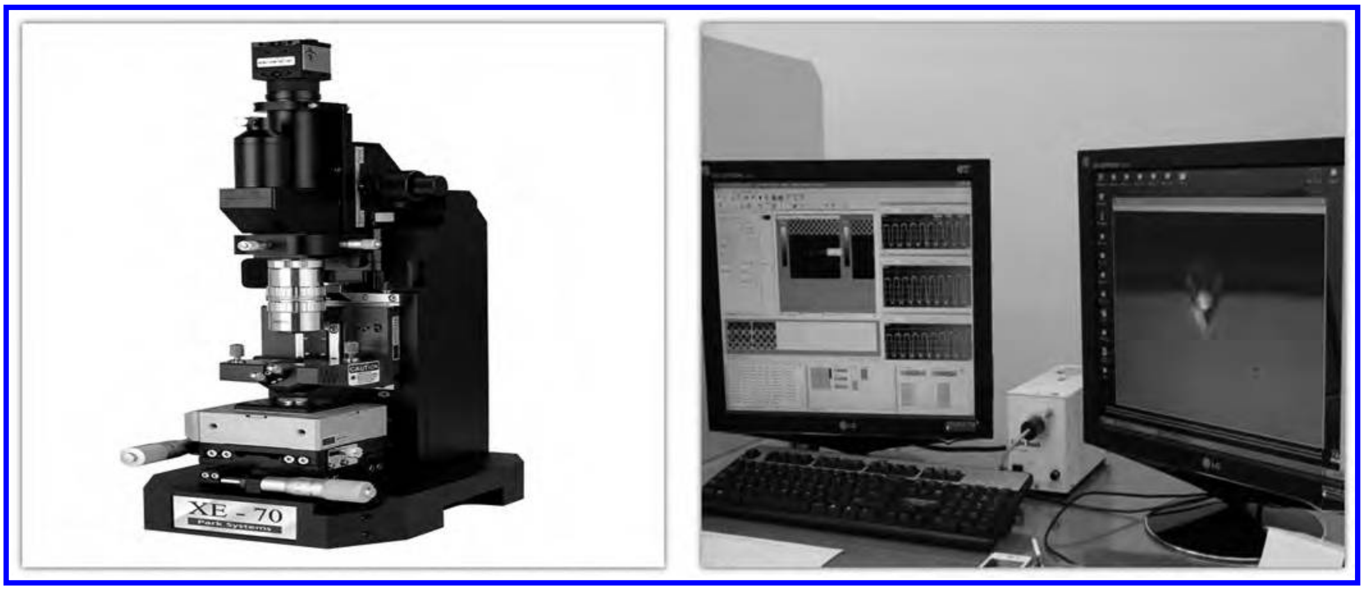

Figure 1. AFM scanning system and software.

Figure 2. Observation of water droplets on a lotus leaf.

○ Materials & Methods

An AFM activity should be unknown and challenging to students (i.e., students should not be able to simply guess micro-nanostructure features of a sample prior to scanning and examination). With this in mind, we selected the topic "cohesion of water drops on a lotus leaf" and designed the following lesson, which we call "Explore the Secrets of a Lotus Leaf Using AFM." At each step, students record their activities and findings on a worksheet (see Appendix). The AFM used in our study was manufactured by Park Systems Corporation (model no. XE_70).

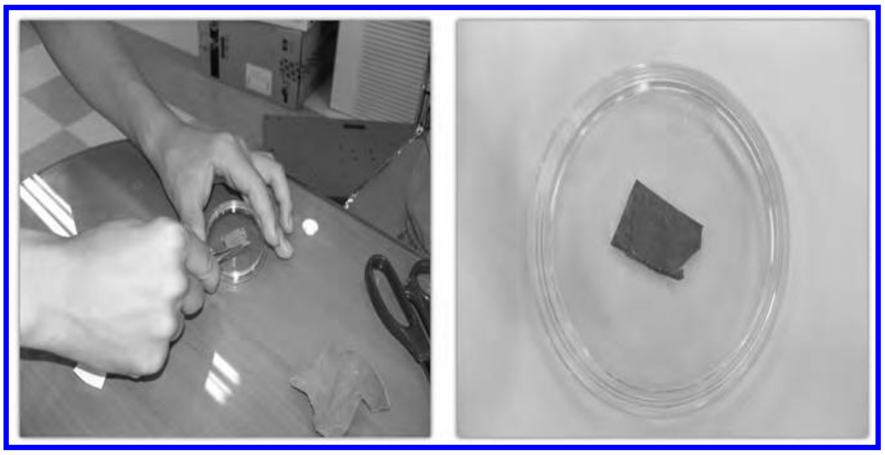

Figure 3. Making a lotus leaf sample.

Step 1: Observation

The teacher begins the lesson by showing photos and video clips of the cohesion phenomena of water droplets on a lotus leaf. Students then allow droplets to drip onto lotus leaves (Figure 2), which were acquired from a lotus field prior to the onset of the class, and observe what happens.

Step 2: Generating Causal Questions

Students are asked to generate various causal questions for the phenomena they observed and share them with the class. For example, they might generate questions like "Why do the water droplets not spread across the lotus leaf?"

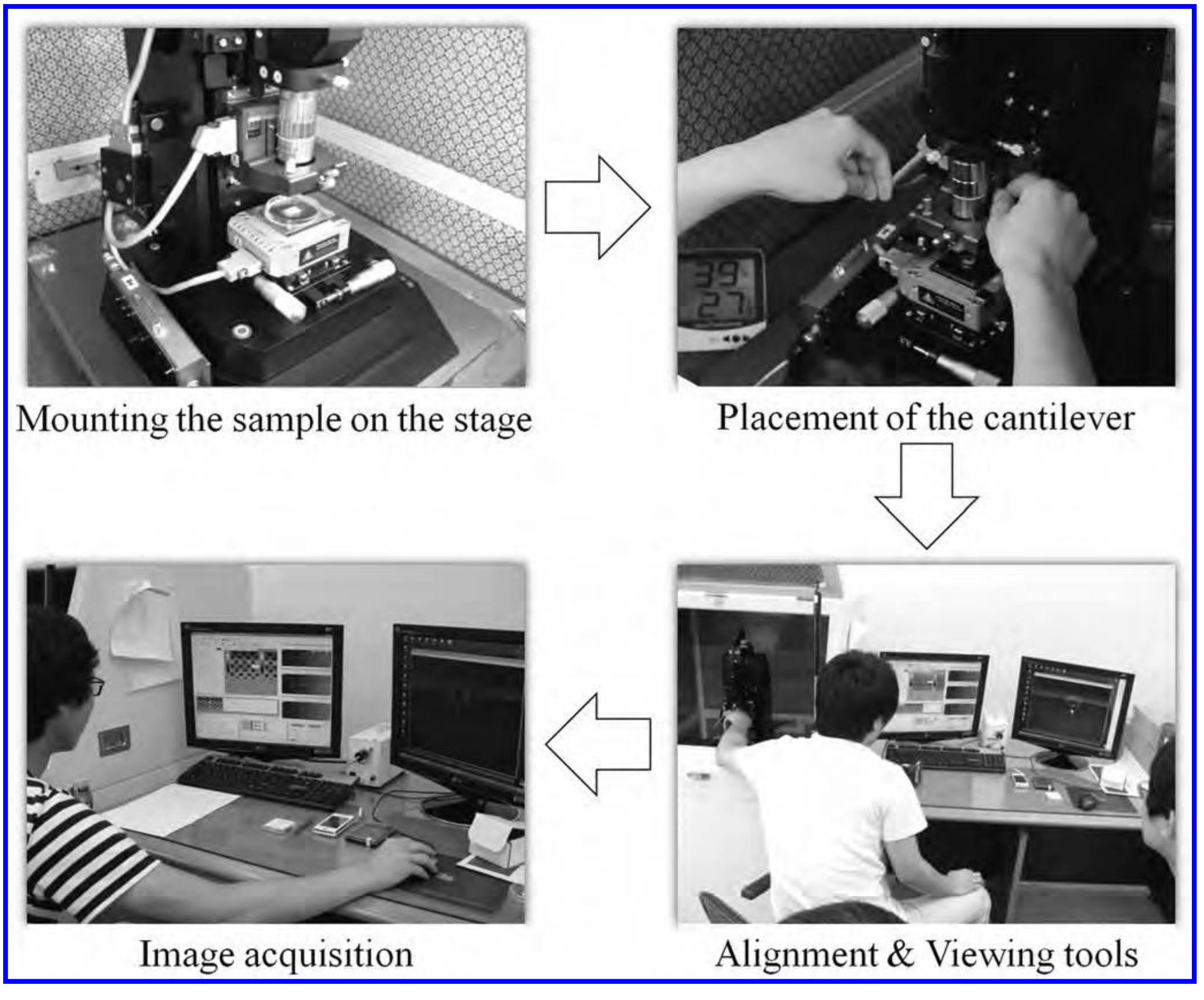

Figure 4. AFM system operation.

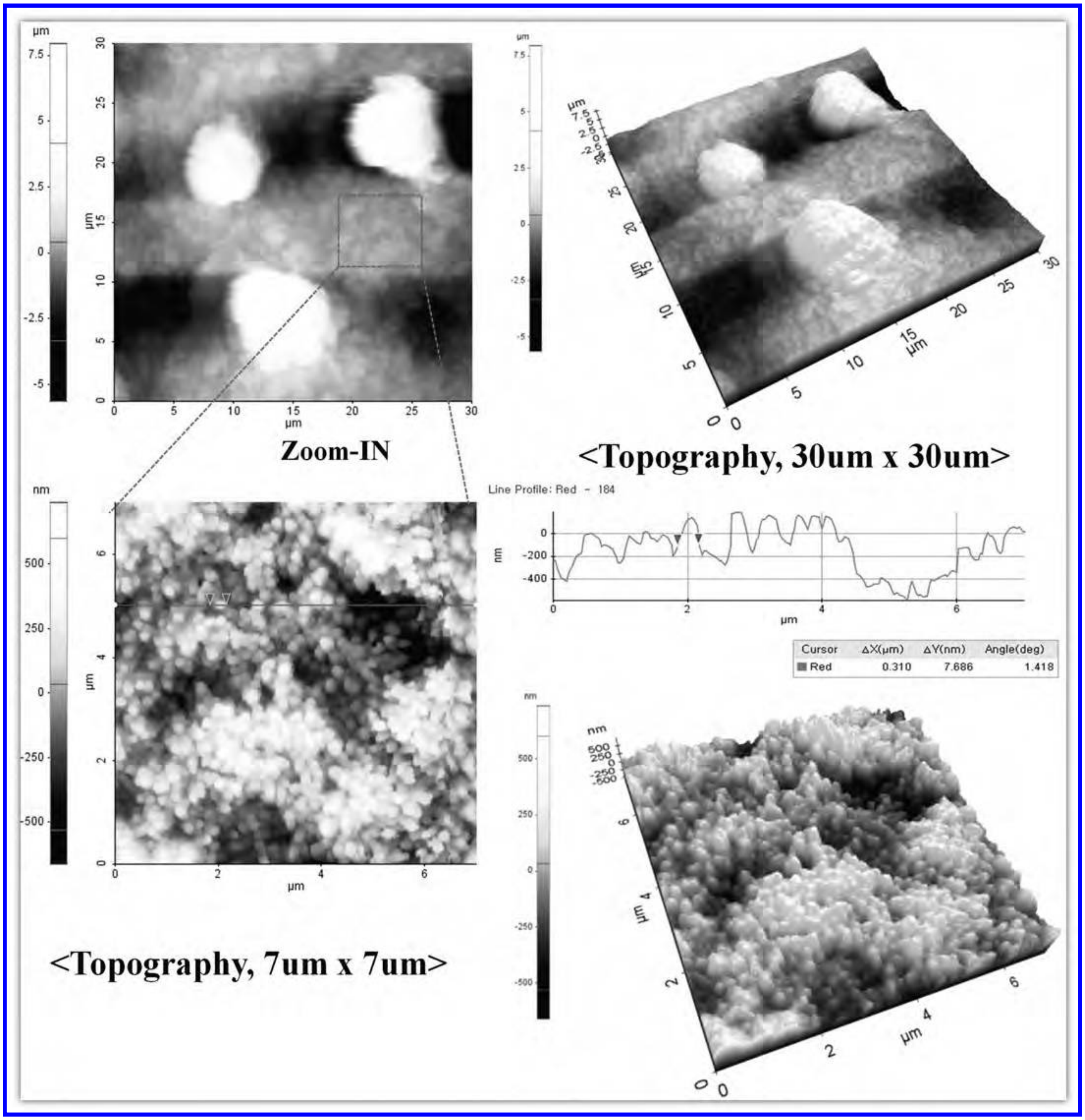

Figure 5. Observed micro-nanostructure of a lotus leaf by students.

Next, the teacher guides the students to select appropriate causal questions from among the diverse questions offered by students.

Step 3: Generating Hypotheses

To address structure-related causal questions, students generate surface-structure conjectures by drawing lotus leaf surface structures. They orally present their imagined structures to the class and then use their imaginary surface structures to generate hypotheses for their causal questions.

Step 4: Testing Hypotheses

Students test their hypotheses by comparing their generated surface structures to the AFM-generated image. In order to accomplish step 4, students produce a lotus leaf sample that can be used by an AFM scanning system. The production process of an AFM sample is simpler than the production process of an optical microscope sample, yet more complicated than the sample creation process for an electron microscope. First, students prepare a lotus leaf sample. An appropriate sample size should approximate a 1 × 1 cm

Table 1. Student proposals for casual explanation and application design.

	Student (n = 8) Proposals
Causal Explanation	Smooth and soft surface of lotus leaf Outer grain of leaf Furrow, structure of rough leaf Thin fur Promontory structure for waterproof Waterproof function by small promontory structure Promontory furrow of surface smaller than a water drop Movement of leaf with promontory structure
Application Design	Sand paper Rough surface None Umbrella, raincoat, outer wall Waterproof clothes, glass of building, house roof Glass, raincoat, umbrella, surface of vehicle, glasses Paint Paint, umbrella, difficult surface to clean

square. Students then attach the lotus leaf sample to a Petri dish using double-sided adhesive tape to ensure that the surface shape is not distorted from pressure placed upon it by the AFM cantilever (Figure 3).

After the lotus leaf sample has been prepared, students place the sample on the AFM stage. Once activated, the AFM system will then generate a micro-nanostructure of the lotus leaf's surface. Figure 4 illustrates the process of acquiring a nano-structure image of a lotus leaf.

Once the micro-nanostructure has been generated, students can directly observe a lotus leaf's surface micro-nanostructure. Students can carefully analyze the lotus leaf's surface micro-nanostructure through operations such as zoom-in, zoom-out, 2D, 3D, and so on to facilitate comparison of their imagined structures (Figure 5). Students are then requested to postulate "what" is needed to maintain water droplets on the surface of a lotus leaf. Knowing the leaf's surface micro-nanostructure, they are also asked to speculate on why water droplets do not spread out all over the surface of a lotus leaf but flow as individual water droplets. Once students have formulated the special structure of a lotus leaf using AFM, the teacher explains (1) the physical characteristics of the small protrusions on a lotus leaf, (2) a lotus leaf's self-cleaning property, and (3) the super-hydrophobic micro-nanostructure of a lotus leaf's surface, which results from the small protrusions on the leaf.

Step 5: Designing a Real-World Application

The teacher leads the students to ponder authentic engineering applications using scientific knowledge about the micro-nanostructure of a lotus leaf's surface. Students design and discuss their engineering applications with one another. In these discussions, students should be guided to investigate both the advantages and the disadvantages of their engineering applications based on the micro-nanostructure of the surface of a lotus leaf.

Step 6: Confirmation of a Possible Application

At this step, the teacher provides students the opportunity to orally present to the class their application designs. In addition to presenting their designs, students need to validate their explanations using knowledge attained from their causal questions and hypotheses. The teacher should then assess the design in terms of real-world biomimetic application possibilities. Table 1 presents the study participants' causal explanations of the observed behavior of water droplets on a lotus leaf and applications where a lotus leaf's surface structure could be advantageous.

Step 7: Application Cases

The teacher introduces various biomimetic technology cases that apply the micro-nanostructure of a lotus leaf's surface. Students compare these biomimetic technology applications to their proposed applications. Finally, the teacher lists various real-world areas in which AFM is utilized. That is, the teacher informs the class how AFM provides detailed biological information on cells, bacteria, viruses, DNA, and protein.

○ Discussion & Suggested Applications

The use of AFM in high school biology classes can provide the following advantages. First, students can directly observe a bio-micro-nanostructure, unobservable by optical microscopy. Indirect learning materials such as the structure image of a lotus leaf's surface are easily found in books and on the Internet; however, indirect learning materials do not arouse the same amount of learning interest and motivation in students. Second, science students have the opportunity to postulate how micro-nanostructures of biological samples pertain to engineering – the application of science in engineering – as well as learn varied applications of micro-nanostructures. In other words, this teaching method offers students the opportunity to experience first-hand the future of science technology by fusing science and engineering. Third, experience with this type of learning by high school students could benefit both the sciences and engineering fields. Because of their prior experience using advanced equipment such as an AFM, the students' futures as scientists or engineers could be greatly enhanced. Although a comprehensive AFM system is too large for the classroom, the mobile AFM specifically developed for education that we used in this study is very convenient, easy to use, and portable.

○ Acknowledgments

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Appendix. Student worksheet.

1. What did you observe?
2. What causal questions would you like to ask about your observed findings?
3-1. What imagined structures can you create to answer your causal questions?
3-2. What hypotheses can you generate for your causal questions based on your imagined structures?
4. What conclusion can you draw from comparing the AFM resultant structure with your imagined structures?
5. What real-world applications do you envision for your conclusion?