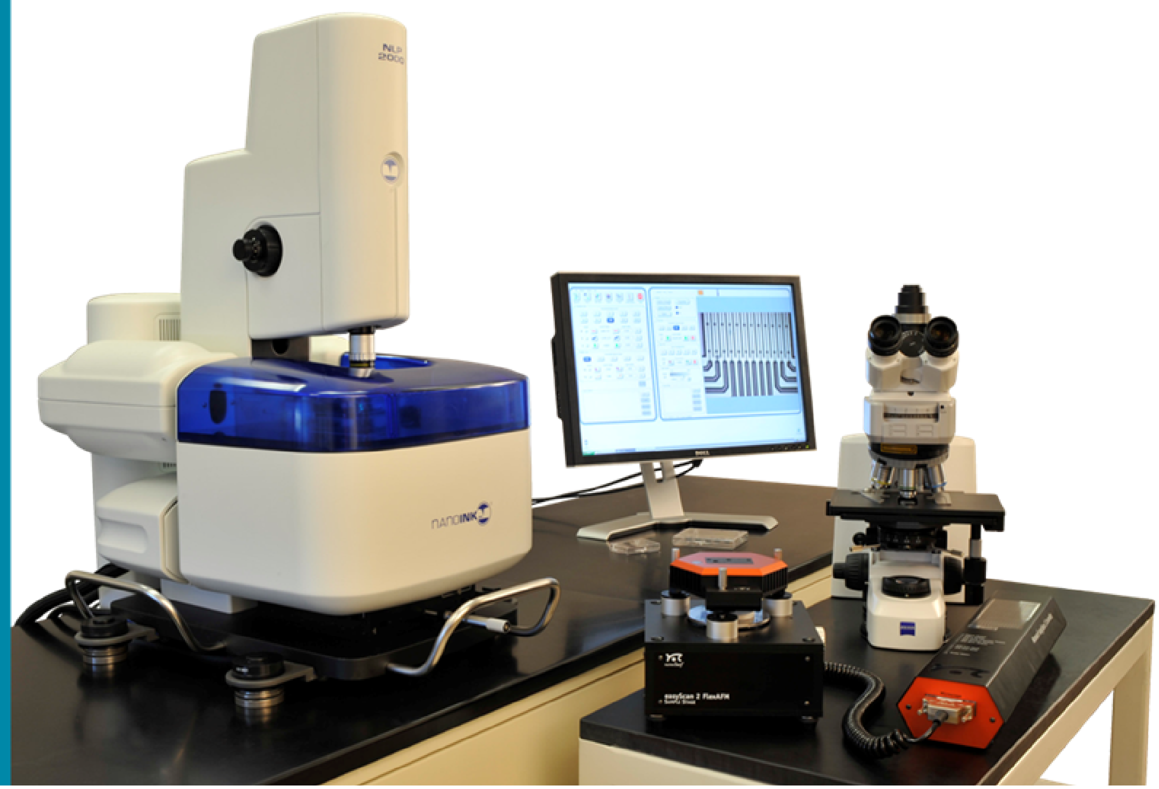
NanoProfessor 101

nanoPROFESSOR™
Hands-On Nanotechnology Education

Excerpts from the

Student Lab Guide



LAB 1

How Smooth Is Smooth at the Nanoscale?

An Exploration of Surface Roughness at the Nanoscale

PRE-LAB CHALLENGE

Your challenge is to identify the *smoothest* and flattest everyday object that you can find. You will do this on your own, or as part of a group to which you have been assigned by your instructor. You will then check the smoothness of the object's surface at the nanoscale in the lab.

Do smooth surfaces really exist?

What makes an everyday object feel smooth to the touch? Imagine a concrete countertop, one made of polished granite, and another of stainless steel. Which of the three do you perceive as the smoothest? More importantly, *how* do you perceive their smoothness? Are you just describing your visual experience or the tactile experience of your fingertips as they make contact against the surface? What is it about these surfaces that you are able to perceive in terms of their texture? And, most importantly, what happens to the perceived smoothness of everyday objects and materials when observed at the nanoscale?

The purpose of this introductory lab is to explore how material properties at the macroscale differ from those at the nanoscale. When approaching the nanoscale, surface structures become increasingly important for interactions. In this lab, you will compare materials you bring in with a gold substrate used for patterning at the nanoscale.

LAB 2

Leveling the Playing Field

Humans and Machines Working Together at the Nanoscale

LAB CHALLENGES

- Accuracy and precision
- Steadiness
- Manipulating tiny objects
- Using sensitive equipment to navigate surfaces in micron and nanometer increments

Why is it important to work on a level surface?

Just as surgeons must prepare patients, surgical tools, and themselves for surgery, so too must scientists and technicians prepare to execute a pattern at the nanoscale. Surfaces and substrates must be prepared, staged, controlled, *leveled* and maintained. Biological, chemical, and physical materials need to be unpacked, moved, created, cultured, and mixed. Tools must be assembled, supplied, calibrated, tested, and re-calibrated – all before the operation can commence. The scientist – in white lab coat and latex gloves – must work with precision, steadiness, control, flexibility, and demonstrate insight, even leadership... *but* at a scale that is in some respects more challenging than that of the surgeon. Like a chess master who thinks three steps ahead, scientists working at the nanoscale must predict, foresee, imagine, and then manipulate tiny objects and machines with nanoscale precision, *often within spaces that are not visible to the human eye*.

Lab 2 requires you to confront the challenges that all scientists working at the nanoscale must: unsteady hands; materials that require extremely high levels of purity; imperfect surfaces (which appear smooth at the microscale but are not so smooth at the nanoscale); highly precise and responsive equipment that does *exactly* what you tell it to do (often leaving no room for error); ”seeing“ or imaging something that is invisible to the naked eye; predicting what might be on a surface before anyone has had an opportunity to really measure what’s there.

Still, with a sense of adventure and a mind open to new ideas, scientists and engineers can use extraordinary technologies, machines, and problem-solving skills to push into this new, exciting, and challenging *nano realm*.

LAB 3

PRE-LAB CHALLENGE

Practice using a micropipette to deposit 2 μL, 1 μL and 0.5 μL of water onto a glass slide. Perform the same operation using oil, soap, syrup, glycerin, or other fluids. *Remember* to change the pipette tip for each fluid used. Notice how easy or hard it is to get the drop of fluid to release from the pipette tip. Do drops stick to the *outside* of the pipette, or is there adhesion between the fluid, slide, and tip as you deposit the fluid? If so, the substrate (the glass slide or the inkwell) can stick to the pipette tip (with the fluid acting as the glue).

Now practice the same procedure using inkwells provided by your instructor. Use a volume of 1 μL only for this part of the challenge. Place a drop of each type of fluid into separate inkwells. Observe how much adhesion can exist between the fluid and the pipette tip, or the fluid and the inkwell. Remember: the inkwell should never move.

What methods might you invent to improve your steadiness and accurate placement of a drop of fluid into an inkwell?

Going with the Flow

Fluidics and the Forces at Work at the Micro and Nanoscales

Do fluids work differently at the nanoscale?

How do fluids work at the nanoscale? What properties do they display at different scales? How do viscosity and other forces play a role in the way fluids flow at different scales? What happens when fluids are placed in micro or nanochannels? How strongly do their molecules interact with the material in a channel or on a surface? How can we measure or quantify flow at the micro and nanoscales? Finally, why is our knowledge concerning how fluids work at the nanoscale *important*?

Fluid dynamics at the nanoscale present unique experimental and theoretical challenges. In this lab, you will have an opportunity to practice micropipetting, making observations, and performing data collection by considering aspects of fluid flow at the nanoscale. You will observe fluids of different viscosities flowing through microchannels and evaluate their behavior. This lab also provides you with practical equipment experience.

LAB 4

PRE-LAB CHALLENGE

The world around us is filled with compelling examples of diffraction, reflection, and refraction. Your pre-lab challenge is to bring in real-world examples of each (physical objects, or perhaps descriptions from personal experience) to share with your classmates. In your view, what are the most compelling or unique differences among these three important and sometimes overlapping concepts?

Reflecting on Light

Creating Patterns and Diffraction Gratings at the Nanoscale

Can structures that are invisible to the human eye or an optical microscope still affect light?

Is it possible to make and view nanoscale patterns that are smaller than actual visible light wave length? If so, by what means? How do scientists measure and view light waves and other photonic phenomena at the nanoscale? Does light behave differently at the nanoscale? What about diffraction, especially with regard to lightwave transmission and reflection? Can light be directed around objects in a way that causes them to disappear from sight?

When it comes to light and light waves, the type of interaction and the interaction itself between electromagnetic waves (light) and an object is significantly impacted by the relationship between the size of the object and the wavelength of the light impinging upon the object. Will your gratings allow you to manipulate light at the nanoscale? Students will investigate how the dimensions of a diffraction grating influence the observed color spectrum.

LAB 5

PRE-LAB CHALLENGE

Self-assembled monolayers (SAMs) are starting to appear in every-day household products. Which current products use SAMs? Can you find a sample of a household product that uses SAMs and examine it with your classmates in the lab? Which other new products are currently in development? Can you imagine any new uses of SAMs that you'd like to further investigate?

The Ties that Bind

Creating Chemical Structures Such as Self-Assembled Monolayers (SAMs) on Surfaces

How do molecules self-assemble to create monolayers at the Nanoscale?

When you fabricate using self-assembled monolayers, what are the relevant issues? How can we use a gold substrate and an alkyl thiol ink to create a SAM? How does a dry,"dip-coated" ink transfer from tip to surface, and what role does humidity play? Finally, how do hydrophobicity and hydrophilicity impact the inking and assembly processes?

In *Lab 5*, investigate how organosulfur compounds such as alkyl thiols can be used as "inks" to prepare SAMs on gold surfaces. Pattern 16-mercaptohexadecanoic acid (MHA) using the NLP 2000,and then backfill the bare gold surface with 11-mercapto-1-undecanol (MOU). Then, examine the patterned shapes, size, and height of the MHA SAM *via* AFM. Is there a correlation between height, size, and shape of patterned MHA and the amount of *dwell* or contact time that tips remain on the gold surface during patterning?

LAB 6

PRE-LAB CHALLENGE

According to the International Union of Pure and Applied Chemistry (IUPAC), a bio-sensor is a "device that uses specific biochemical reactions mediated by isolated enzymes, immunosystems, tissues, organelles or whole cells to detect chemical compounds usually by electrical, thermal or optical signals." What are some common bio-sensors in use today? Can you bring one into class and demonstrate how it works? Why is it important to study or research biodetection at the nanoscale? What future possibilities exist for advancement in this important arena?

Molecular Detection Using DNA

Creating a Bio-sensor with DNA Arrays

Why are molecular patterns and their recognition important in the creation of a bio-sensor?

What role might DNA, a DNA array, or complementary strands of DNA play within a nanoscale bio-sensor? From the perspective of a scientist working at the nanoscale, how do chemical, biological, and physical forces work together to create such bio-detection systems? How can the NLP 2000 be used to create a DNA-sensor device?

In *Lab 6*, the *thiol linker* chemistry (studied in *Lab 5*) is extended to the nanopatterning of biologically-relevant molecules in the form of bioarrays that use strands of chemically-modified DNA (*modified* with a thiol group). The height and hydrophobic/hydrophilic nature of the DNA SAM is examined *via* AFM after backfilling with octadecanethiol (ODT). A complementary strand of fluorophore-tagged DNA is then added to the DNA self-assembled monolayer (SAM). Do results from the experiment demonstrate DNA's ability to recognize and bind with its complementary strand *in a reversible fashion*? If so, does such work with DNA inform the chemist in the pursuit of more sophisticated biomedical detection systems?

LAB 7

PRE-LAB CHALLENGE

How is nanobiology currently used to solve important problems? Enzyme-linked immunosorbent assay (ELISA), for example, is a biochemical method used to diagnose diseases. The creation and use of protein microarrays and biomimetic surfaces for gene expression and implantology are also examples. Why is it important to study or research nanobiology? And what future possibilities exist for advancement in this important area of research, biotechnology, and nanoscience?

Membranes and Proteins

Creating Patterns with Phospholipids and Proteins

How do proteins bind to functionalized lipids?

Why is a nanoscale perspective important for biology, especially if we consider *biological* fields of biochemistry, molecular biology, and biophysics? Which tools can be used to observe the structures that enable life? What role does water play in biology at the nanoscale? How does pH and ionic strength affect biomolecular functions? What are the functions of bio-molecules such as DNA, amino acids, peptides, proteins, lipids, phospholipids, and carbo-hydrates? In a biological system, what holds everything together? Which forces attract objects in some cases and repel objects from one another in others? How do structures within and around a cell relate to their function? And lastly, why are the membranes of a cell *fluid*?

In *Lab 7*, you will investigate, observe, and control biological lipids in water and specific protein binding. You'll learn about the fluid nature of lipid membranes while observing how phospholipids behave in water where they self-organize to form the bilayer structure of cell membranes. You will also demonstrate how functional nano- and micro-structured membrane systems can now be reconstituted in the laboratory with sub-cellular resolution. As an example, you'll study specific binding of streptavidin protein to biotinylated phospholipids.

LAB 8

PRE-LAB CHALLENGE

How do cells interact and adhere to the world of surfaces around them? Before starting this lab, list examples or scenarios – or better yet, bring in living *examples* – of cells adhering to surfaces. What sorts of possible future technologies might be developed based on the examples or samples you uncover?

Sticky Situations

Using Patterns to Control Living Organisms

How do cells interact as they adhere to surfaces in a nano-structured environment?

What role do nano- and micro-structured surface textures play when cells adhere to surfaces? How and why do cells *move* within those environments? Living systems do things for all kinds of reasons: what are *the reasons* why some cells adhere to surfaces while other do not? How do these reasons relate to the concept of a biological function? What role does cell culture play in helping us to answer these questions? And finally, how can our understanding of cell *adhesion* lead to the development of applications in real world?

In *Lab 8*, you will observe and investigate how cells adhere to chemically-functionalized surfaces by way of studying patterns on the scale of individual cells. Cell adhesion to a surface is a fundamental biological process with applications ranging from medicine to agriculture to *biofouling*. Cells in their natural environments (*in vivo*) interact with surfaces that have highly heterogeneous and diverse textures. Studies of cells grown in culture (*in vitro*) on artificially nano- and micro-structured surfaces can provide important insights into nanobiology. In this lab, you will gain experience handling and observing *living* bacteria cells in a nano-structured environment.