Nano Roughness

Topic
Microscopy, Roughness Measurement, and Estimation and Mathematical Reasoning

Key Question
How do you measure roughness of the Atomic Force Microscopy images of the nanoscale material?

Learning Goals
Students will:
• Use numeric and visual data to create a reasonable measurement scheme
• Consider how to use and exclude data
• Work in dissimilar measurement scales, convert between scales
• Modify an existing procedure or create a new procedure for quantifying roughness of nano-scale images
• Make decisions about whether or not a solution meets the needs of a client
• Communicate the solution clearly to the client

Guiding Documents
This activity has the potential to address these and other ABET engineering standards, as well as address math and science principles.

ABET Standards, Criterion 3, Outcomes:
(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Recommended supplies for all MEAs
It is recommended to have all of these supplies in a central location in the room. It is recommended to let the students know that they are available, but not to encourage them to use anything in particular.

• Rulers
• Calculators
• Overhead transparencies and transparency markers/pens, whiteboards and markers, posterboards, or other presentation tools such as a document camera.
• Optional: Computers with programs such as Microsoft Word and Excel

What are Model Eliciting Activities (MEAs)?
Model-Eliciting Activities are problem activities explicitly designed to help students develop conceptual foundations for deeper and higher order ideas in mathematics, science, engineering, and other disciplines. Each task asks students to mathematically interpret a complex real-world situation and requires the formation of a mathematical description, procedure, or method for the purpose of making a decision for a realistic client. Because teams of students are producing a description, procedure, or method (instead of a one-word or one-number answer), students’ solutions to the task reveal explicitly how they are thinking about the given situation.
The Nano Roughness MEA consists of four components:

1) Background Reading (Pre-Reading): Students individually read the newspaper article to become familiar with the atomic force microscope of the problem. This is often assigned as out-of-class reading. This handout is on pages 14-15.

2) Nano Roughness Individual Activities: Students individually read the company profile and answer the reading comprehension and probing questions about the background reading to become even more familiar with the context and beginning thinking about the problem. This handout is on pages 6-10.

3) Nano Roughness Team Activity: In teams of three or four, students work on the problem statement for approximately 45 - 75 minutes. The time range depends on the amount of self-reflection and revision you want the students to do. It can be shorter if you are looking for students' first thoughts, and can be longer if you expect a polished solution and well-written letter. The handouts are on pages 11-13.

4) Process of sharing solutions: Each team writes their solution in a letter or memo to the client. Then, each team presents their solution to the class. Whole class discussion is intermingled with these presentations to discuss the different solutions, the mathematics involved, and the effectiveness of the different solutions in meeting the needs of the client.

In totality, each MEA takes approximately 2-3 class periods to implement, but can be shortened by having students do the individual work during out-of-class time. The Presentation Form can be useful and is explained on page 4 and found on page 17.

Recommended Progression of the MEA

While other implementation options are possible for MEAs, it is recommended that the MEA be implemented in a cooperative learning format. Numerous research studies have proven cooperative learning to be effective at improving student achievement, understanding, and problem solving skills. In this method students will complete work individually (Newspaper article and readiness questions; as well as initial thoughts on the problem statement) and then work together as a group. This is important because brainstorming works best when students have individual time to think before working as a group. Students can be graded on both their individual and group contributions. Social skills’ discussion at the beginning of the MEA and reflection questions at the end of the MEA are also essential aspects of cooperative learning.

Social Skills (3 - 5 minutes)

Students must be taught how to communicate and work well in groups. Several social skills that are essential to group work are decision-making, asking questions, and communicating and listening. The teacher can show part of a YouTube video and discuss aspects of these skills before beginning the MEA.

(http://www.youtube.com/user/flowmathematics)

Newspaper Article and Readiness Questions:
The purpose of the newspaper article and the readiness questions is to introduce the students to the context of the problem.

(10 minutes): Give the article and the questions to the students the day before for homework. Then, in the next class, discuss as a class the answers to the readiness questions before beginning to discuss the problem statement.

Problem Statement:

You may want to read the problem statement to the students and then identify as a class: a) the client that the students are working for and b) the product that the students are being asked to produce. Once you have addressed the points above, allow the students to work on the problem statement. Let the students know that they will be sharing their solution to the rest of the class. Tell students you that you will randomly pick a group member to present for each group. Tell the
students that they need to make sure that everyone understands their group’s solution so they need to be sure to work together well. The group member who will present can be picked by assigning each group member a number.

**Working on the Problem Statement** (35-50 minutes): Place the students in teams of three or four. Students should begin to work by sharing their initial ideas for solving the problem. If you already use teams in your classroom, it is best if you continue with these same teams since results for MEAs are better when the students have already developed a working relationship with their team members. If you do not use teams in your classroom and classroom management is an issue, the teacher may form the teams. If classroom management is not an issue, the students may form their own teams. You may want to have the students choose a name for their team to promote unity.

**Teachers’ role:** As they work, your role should be one of a facilitator and observer. Avoid questions or comments that steer the students toward a particular solution. Try to answer their questions with questions so that the student teams figure out their own issues. Also during this time, try to get a sense of how the students are solving the problem so that you can ask them questions about their solutions during their presentations.

**Presentations of Solutions** (15-30 minutes): The teams present their solutions to the class. There are several options of how you do this. Doing this electronically or assigning students to give feedback as out-of-class work can lessen the time spent on presentations. If you choose to do this in class, which offers the chance for the richest discussions, the following are recommendations for implementation. Each presentation typically takes 3 – 5 minutes. You may want to limit the number of presentations to five or six or limit the number of presentations to the number of original (or significantly different) solutions to the MEA.

Before beginning the presentations, encourage the other students to not only listen to the other teams’ presentations but also to a) try to understand the other teams’ solutions and b) consider how well these other solutions meet the needs of the client. You may want to offer points to students that ask ‘good’ questions of the other teams, or you may want students to complete a reflection page (explanation – page 4, form – page 17) in which they explain how they would revise their solution after hearing about the other solutions.

As students offer their presentations and ask questions, whole class discussions should be intermixed with the presentations in order to address conflicts or differences in solutions. When the presentations are over, collect the student teams’ memos/letters, presentation overheads, and any other work you would like to look over or assess.

**Assessment of Students’ Work**

You can decide if you wish to evaluate the students’ work. If you decide to do so, you may find the following Assessment Guide helpful:

**Performance Level Effectiveness:** Does the solution meet the client’s needs?

- **Requires redirection:** The product is on the wrong track. Working longer or harder with this approach will not work. The students may need additional feedback from the teacher.

- **Requires major extensions or refinements:** The product is a good start toward meeting the client’s needs, but a lot more work is needed to respond to all of the issues.

- **Requires only minor editing:** The product is nearly ready for the client to use. It still needs a few small modifications, additions, or refinements.

- **Useful for this specific situation:** No changes are necessary to meet the client’s immediate needs.

- **Share-able or re-usable:** The tool not only works for the immediate solution, but it would be easy for others to modify and use in similar
Implementing an MEA with Students for the First Time

You may want to let students know the following about MEAs:

• MEAs are longer problems; there are no immediate answers. Instead, students should expect to work on the problem and gradually revise their solution over a period of 45 minutes to an hour.
• MEAs often have more than one solution or one way of thinking about the problem.
• Let the students know ahead of time that they will be presenting their solutions to the class. Tell them to prepare for a 3-5 minute presentation, and that they may use overhead transparencies or other visuals during their presentation.
• Let the students know that you won’t be answering questions such as “Is this the right way to do it?” or “Are we done yet?” You can tell them that you will answer clarification questions, but that you will not guide them through the MEA.
• Remind students to make sure that they have returned to the problem statement to verify that they have fully answered the question.
• If students struggle with writing the letter, encourage them to read the letter out loud to each other. This usually helps them identify omissions and errors.

Observing Students as They Work on the Nano-Roughness MEA

You may find the Observation Form (page 16) useful for making notes about one or more of your teams of students as they work on the MEA. We have found that the form could be filled out “real-time” as you observe the students working or sometime shortly after you observe the students. The form can be used to record observations about what concepts the students are using, how they are interacting as a team, how they are organizing the data, what tools they use, what revisions to their solutions they may make, and any other miscellaneous comments.

Presentation Form (Optional)

As the teams of students present their solutions to the class, you may find it helpful to have each student complete the presentation form on page 17. This form asks students to evaluate and provide feedback about the solutions of at least two teams. It also asks students to consider how they would revise their own solution to the Paper Airplane MEA after hearing of the other teams’ solutions.

Student Reflection Form

You may find the Student Reflection Form (page 18) useful for concluding the MEA with the students. The form is a debriefing tool, and it asks students to consider the concepts that they used in solving the MEA and to consider how they would revise their previous solution after hearing of all the different solutions presented by the various teams. Students typically fill out this form after the team presentations.

Common Core Math Standards

HS. N.Q.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

HS.N.Q.2 Define appropriate quantities for the purpose of descriptive modeling.

HS.N.Q.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

HS.G-MG.3 Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).
HS.S-IC.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.

### Standards for Mathematical Practices integration with MEAs

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<tr>
<th>Mathematical Practice</th>
<th>How it occurs in MEAs</th>
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<td>1. Make sense of problems and persevere in solving them.</td>
<td>As participants work through iterations of their models they continue to gain new insights into ways to use mathematics to develop their models. The structure of MEAs allows for participants to stay engaged and to have sustained problem solving experiences.</td>
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<td>2. Reason abstractly and quantitatively</td>
<td>MEAs allow participants to both contextualize, by focusing on the real world context of the situation, and decontextualize by representing a situation symbolically.</td>
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<td>3. Construct viable arguments and critique the reasoning of others.</td>
<td>Throughout MEAs while groups are working and presenting their models.</td>
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<td>4. Model with mathematics.</td>
<td>This is the essential focus of MEAs; for participants to apply the mathematics that they know to solve problems in everyday life, society, or the workplace. This is done through iterative cycles of model construction, evaluation, and revision.</td>
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<td>5. Use appropriate tools strategically.</td>
<td>Materials are made available for groups as they work on MEAs including graph paper, graphing calculators, computers, applets, dynamic software, spreadsheets, and measuring devices.</td>
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<td>6. Attend to precision.</td>
<td>Precise communication is essential in MEAs and participants develop the ability to communicate their mathematical understanding through different representations including written, verbal, symbolic, graphical, pictorial, concrete, and realistic.</td>
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<td>7. Look for and make use of structure.</td>
<td>Participants in MEAs can use their knowledge of mathematical properties and algebraic expressions to develop their solutions.</td>
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<td>8. Look for and express regularity in repeated reasoning.</td>
<td>As participants develop their models the patterns they notice can assist in their model development.</td>
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Company Profile – Liguore Laboratories

Liguore Laboratories is an up-and-coming technology company founded in 1996 to develop materials that improve performance and extend the life of coated orthopedic and biomedical implants. The materials are called nanostructured materials because they are so small that it is necessary to use a very high powered microscope to view images of them. The coating of orthopedic implants, such as joint replacement, is done in order to either increase the life of the implant materials or provide an implant surface that is more compatible with the human body in order to decrease the chance of rejection. Our company also produces coatings for biomedical devices such as bone screws, fixation devices, and bone spacers.

Liguore Laboratories uses special coating techniques to apply a full range of coatings to orthopedic and biomedical implants made by several manufacturers around the world. The coatings include titanium, hydroxyapatite, alumina/titania, gold, calcium phosphate, and other metal alloys. Our company has met and exceeded all industry and health standards for the United States and Europe. One of our more recent developments is the use of gold to coat bone screws. Liguore Laboratories scientists found that gold, when heated, makes a smooth surface coating for implants. The screws coated with smooth gold had more compatibility with the body than bone screws coated with stainless steel.

Research about coatings for artificial hip replacements is a new project for our company. Recently a physicist from University of Alabama, Birmingham named Dr. Yogesh Vohra accidentally produced smooth diamond. When making manmade diamond crystals in a laboratory, the gas reactor sprang a small leak and let air into the mixture. Nitrogen from the air reacted with the carbon of the diamond. The diamond mixture created was smooth and adhered very easily to metal. Because diamond is durable, it makes a very good candidate for coating artificial hip replacements. The current coatings wear down or loosen from constant use after about 10 years, which could mean more surgery for the recipient. The diamond coating is projected to last around 40 years which would improve the comfort and health of the patient.

Liguore Laboratories is on the cutting edge of technology in the biomedical coatings industry. Our mission is to create medical device coatings that provide performance and durability.

Questions to Get You Started:

1. What does Liguore Laboratories do?
2. Why is gold used to coat bone screws?
3. Who will benefit from the discovery of a way to make smooth diamond coatings?
Atomic Force Microscope (AFM) Background Information

Topographical Maps

Below is a topographical map of Colorado. As you look at the map, keep in mind that the Rocky Mountains are in the western part of Colorado. The key to the right of the map provides information on how high the terrain is above sea level. Notice that the peaks of the mountains are the lightest white and pink shades and the valleys between the mountains and the plains are the darkest green shade.
Smooth Diamond Images

The images that the Atomic Force Microscope produces are like topographical maps. The color of the image represents the height of the material. The lighter parts of the image are higher. The two images are images of smooth diamond from Dr. Vohra’s lab. Image A is a 3-dimensional side-view of the diamond sample. The bar on the right indicates the height of the diamond surface. Image B (on the next page) is a top-view image of the diamond. Remember that nanometers are very small. One nanometer is $10^{-9}$ of a meter or one billionth of a meter. The human eye can only detect things that are bigger than 100 nanometers. An Angstrom is a unit of measurement that is approximately the size of one atom.

Image A