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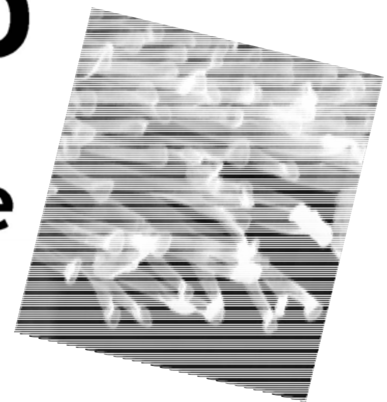
# NanoLeap into New Science



# *Exploring the Mystery of the Gecko*

# Physical Science Teacher Guide

**February 2009**

This work is supported by the National Science Foundation, Division of Elementary, Secondary and Informal Education award # ESI-0426401

# *Investigating Static Forces in Nature: The Mystery of the Gecko* Physical Science Module

## *Preface*

### What Is the *NanoLeap* Physical Science Module?

The *NanoLeap* project represents an approach for teachers to introduce the exciting world of nanoscale science and technology to their classes by integrating interdisciplinary research with traditional science concepts. *Investigating Static Forces in Nature: The Mystery of the Gecko* is a three-week module that replaces and supplements part of a unit that is normally taught at the beginning of a physical science course. It addresses *National Science Education Standards* (NSES)[1] in Science as Inquiry, the Nature of Science, and Physical Science including the topics of static forces, measurement, size and scale, and adhesion. It also extends some of the basics of atomic structure.

While considering the question of adhesion, students learn about the properties of surfaces and the measurement of force interactions. They then apply these concepts at the nanoscale level. Through studying a curious natural phenomenon (How a gecko adheres to a ceiling?), students gain an understanding of forces, adhesion, surface contact, small size and scale, surfaces close-up, instrumentation, and weak atomic interactions. The central question that students will consider throughout the module is: "**What factors affect the strength of the contact forces between interacting surfaces?**"

**Why *NanoLeap*?**

*NanoLeap: Exploring the Mystery of the Gecko* models the way scientists think as they study a real-life phenomenon by asking the same types of questions that biologists, chemists, and engineers have been asking for years. This *NanoLeap* module is intended to motivate students to study a real-world phenomenon and at the same time to give them a better understanding of the role that nanoscale science and technology plays in an ever-changing world. The module provides students with opportunities to develop skills in experimental design that are often a major emphasis in state science assessments.

**Curriculum Fit**

Whether a physical science course begins with chemistry topics or physics topics, *NanoLeap: Exploring the Mystery of the Gecko* fits easily into the curriculum. The module engages students actively in the processes of experimental design, utilizing metric measurements and conversions, and exploring properties of matter. Pilot-test teachers suggested that it would be beneficial for students to have prerequisite knowledge about scientific notation and basic atomic structure prior to beginning this module.

[1] National Research Council (1996). *National science education standards*. Washington, DC: National Academy Press.

| Traditional Sequence | Proposed NanoLeap Placement |
|---|---|
| 1. *Scientific Method/Measurement* | 1. *Introduction to Scientific Method*, *Measurement* |
| 2. Description *of Motion (Velocity/Acceleration)* | 2. *NanoLeap: Exploring the Mystery of the Gecko (Observation, Interpretation, Forces [including electrical, atomic] adhesion, size/scale, modeling, experimentation, instrumentation, drawing conclusions)* The *module* **replaces or supplements Scientific Method and Forces (Net Forces/Friction)** |
| 3. ***Forces (Net Forces/Friction)*** | 3. *Description of Motion (Velocity/Acceleration)* |
| 4. *Forces to Explain Motion (Newton's Laws)* | 4. *Forces to Explain Motion (Newton's Laws)* |

**Learning Cycle and Assessments**

The module employs a modified "Five E" learning cycle where observations and questions are developed in the Engage phase. Investigations are based on new understandings of concepts during subsequent learning experiences in the "Explore, Explain, and Elaborate phases." The Evaluate phase is conducted at the conclusion of the module. Student formative assessments, designed to help teachers make effective instructional decisions, are embedded within each lesson (e.g., reflection journals to assess learning and identify questions and misconceptions early). The summative essay assessment is evaluated using rubrics designed to help students and teachers understand expectations and measure performance against specific criteria.

The following table contains the lesson sequence organized by the learning cycle and lesson objectives. This table also includes how each lesson aligns with the *National Science Education Standards*, the NanoLeap Big Ideas and Essential Understandings, and Multiple Choice Summative Assessment Items.

| Learning Cycle | Lesson Title | Objectives | NSES Content Standards Addressed | *NanoLeap* Big Ideas/Essential Understandings |
|---|---|---|---|---|
| Engage | Lesson 1: How Can a Gecko Walk on a Ceiling? | Make observations, predictions, and interpretations of how the gecko's foot interacts with surfaces | **History and Nature of Science**: Nature of Scientific Knowledge | |
| | | Formulate questions that might be used for further investigations | **Science as Inquiry**: Abilities necessary to do scientific inquiry<br><br>Identify questions | |

| Learning Cycle | Lesson Title | Objectives | NSES Content Standards Addressed | *NanoLeap* Big Ideas/Essential Understandings |
|---|---|---|---|---|
| | | | and concepts that guide scientific investigations | |
| Explore | Lesson 2: What Do We Mean When We Speak About Surfaces in Contact? | Compare the amount of surface contact (real contact) to total unit area (apparent contact)<br><br>Understand that different textures of surfaces have different contact ratios | **Science as Inquiry**: Understandings about scientific inquiry<br><br>Mathematics is essential in scientific inquiry.<br><br>Mathematics' tools and models guide and improve the posing of questions, gathering data, constructing explanations, and communicating results. | **Forces**<br>Electrical and magnetic forces are the most important of the fundamental forces at the nanoscale level.<br><br>Adhesion, the attractive force between two unlike materials, is dependent upon the total area of contact between the materials' surfaces. |
| Explore/ Explain | Lesson 3: What Are Your Ideas About Small Sizes? | Classify and compare objects in different size ranges to have a better understanding of objects at the nanoscale<br><br>Understand relative size of objects at different scales | **Science as Inquiry**: Understandings about scientific inquiry<br><br>Mathematics is essential in scientific inquiry.<br><br>Mathematics' tools and models guide and improve the posing of questions, gathering data, constructing explanations, and communicating results.<br><br>**Physical Science**: The structure of atoms | **Measurement and Size**<br>Imaging and measurement tools allow for detection, characterization, and manipulation of nanostructures.<br><br>Nanoscience is the study of the structure of atoms and molecules with at least one dimension roughly between 1 and 100 nanometers.<br><br>The size of a single atom or small molecule is measured at the nanometer scale. |
| | | Describe nanotechnology, some of its applications, and the positive as well as | **History and Nature of Science:** Science as a Human Endeavor | **Interdisciplinary Nature of Nanoscale Science**<br>The nature of |

| Learning Cycle | Lesson Title | Objectives | NSES Content Standards Addressed | *NanoLeap* Big Ideas/Essential Understandings |
|---|---|---|---|---|
| | | negative impacts of this technology to someone who is not familiar with the subject. | Scientists have ethical traditions.<br><br>Scientists value peer review, truthful reporting about the methods and outcomes of investigations, and making public the results of work. | nanoscale science, technology, and engineering is interdisciplinary.<br><br>The understanding of the properties and interactions of atoms and molecules may lead to advances in biology, chemistry, and physics.<br><br>**Ethical and Social Issues of Nanoscale Science and Technology**<br>Social interactions can occur between scientific and engineering communities and society.<br><br>It is the responsibility of scientists and practitioners to communicate information necessary for the public to make informed decisions. |
| Explain/ Elaborate | Lesson 4: What Do We Learn When We Look More Closely? | Explain how size, structure, and scale relate to surface interactions<br><br>Describe the function of compliant surfaces in regards to adhesion (what happens when a surface of an object is applied to the surface of another object) | **Science as Inquiry**: Understandings about scientific inquiry<br><br>Mathematics is essential in scientific inquiry.<br><br>Mathematics' tools and models guide and improve the posing of questions, gathering data, constructing explanations, and communicating | **Forces**<br>Electrical and magnetic forces are the most important of the fundamental forces at the nanoscale level.<br><br>Adhesion, the attractive force between two unlike materials, is dependent upon the total area of contact between the materials' surfaces. |

| Learning Cycle | Lesson Title | Objectives | NSES Content Standards Addressed | *NanoLeap* Big Ideas/Essential Understandings |
|---|---|---|---|---|
| | | | results. | |
| Explore | Lesson 5: What Types of Forces Can Hold Objects Together? | Describe what happens when a surface of an object is applied to the surface of another object<br><br>Characterize different methods of adhesion<br><br>Evaluate applicability of different methods to explain gecko adhesion | **Science as Inquiry**: Abilities Necessary to Do Scientific Inquiry<br><br>Formulate and revise scientific explanations and models using logic and evidence | **Forces**<br>Electrical and magnetic forces are the most important of the fundamental forces at the nanoscale level.<br><br>Adhesion, the attractive force between two unlike materials, is dependent upon the total area of contact between the materials' surfaces.<br><br>Adhesion mechanisms include: mechanical interlocking, interdiffusion, surface reaction, capillary action, suction, and intermolecular forces. |
| Explore/ Explain | Lesson 6: How MUCH Force Is Needed to Make an Object Stick?<br><br>What Factors Affect the STRENGTH of Force Acting on an Object? | Describe that a net force of zero is necessary for objects to adhere to a surface (wall or ceiling)<br><br>Identify different variables and the constants that affect adhesive forces<br><br>Explain how the amount of adhesion changes when the conditions of the surfaces change | **Physical Science:** Motion and Forces<br><br>Objects change their motion only when a net force is applied.<br><br>Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object. | |

| Learning Cycle | Lesson Title | Objectives | NSES Content Standards Addressed | *NanoLeap* Big Ideas/Essential Understandings |
|---|---|---|---|---|
| Elaborate | Lesson 7: How Do We Measure Forces at the Nanoscale Level? Why Is Merely Looking not Enough? | Compare and contrast model probe instruments with those that are used to make measurements of electric and magnetic forces at the nanoscale (AFM, MEMS) | **Science as Inquiry**: Understandings about scientific inquiry<br><br>Scientists rely on technology to enhance the gathering and manipulation of data.<br><br>New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science.<br><br>**Science and Technology: Abilities of Technical Design**<br><br>Students should be introduced to the roles of models and simulations in these processes. | **Measurement and Size**<br>Imaging and measurement tools allow for detection, characterization, and manipulation of nanostructures.<br><br>Scientific instruments can be used to characterize and measure properties of objects, their structure and surfaces, even if the objects cannot be seen.<br><br>Magnetic and electric forces at the nanoscale level, such as van der Waals forces can be measured experimentally. |
| | | Model how instrument probes can be used to characterize surface interactions | | |
| | | Describe how the topography of a surface relates to adhesion | | |
| | | Interpret graphs of forces at the nanoscale level | | |

| Learning Cycle | Lesson Title | Objectives | NSES Content Standards Addressed | *NanoLeap* Big Ideas/Essential Understandings |
|---|---|---|---|---|
| | | Consider the new evidence about surface topography and seta adhesive forces to evaluate remaining methods of gecko adhesion | **Science as Inquiry**<br>Abilities necessary to do scientific inquiry<br><br>Recognize and analyze alternative explanations and models | |
| Evaluate | Lesson 8: How Can a Gecko Walk on a Ceiling? | Describe the attractive forces between and within molecules that cause the gecko to adhere to a vertical surface | **Physical Science: Motion and Forces**<br>The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel<br><br>**Physical Science: Structure of Atoms**<br>Matter is made of minute particles called atoms, and atoms are composed of even smaller components. | **Properties of Matter**<br>Surface interactions can dominate and changes in properties can arise at the nanoscale.<br><br>Electrical and magnetic forces affect properties of materials, specifically physical and mechanical.<br><br>At the nanoscale level, a large fraction of an object's atoms or molecules are exposed at its surface; therefore, the object's properties are dominated by surface interactions.<br><br>**Forces**<br>Electrical and magnetic forces are the most important of the fundamental forces at the nanoscale level.<br><br>Adhesion mechanisms include: mechanical interlocking, interdiffusion, surface reaction, capillary action, suction, and intermolecular forces. |
| | | Describe how a large number of small forces (van der Waals interactions) at the nanoscale level can add up to macroscopic forces | **Physical Science: Motions and Forces**<br>Most observable forces such as those exerted by a coiled spring or friction may be traced to electric forces acting between atoms and molecules. | |

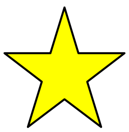
| Learning Cycle | Lesson Title | Objectives | NSES Content Standards Addressed | *NanoLeap* Big Ideas/Essential Understandings |
|---|---|---|---|---|
| | | | | Intermolecular forces act at the nanoscale.<br><br>Van der Waals forces are the only attractive intermolecular forces between two nonpolar, neutral objects.<br><br>**Interdisciplinary Nature of Nanoscale Science**<br>The nature of nanoscale science, technology, and engineering is interdisciplinary.<br><br>The understanding of the properties and interactions of atoms and molecules may lead to advances in biology, chemistry, and physics.<br><br>**Measurement and Size**<br>Imaging and measurement tools allow for detection, characterization, and manipulation of nanostructures.<br><br>Magnetic and electric forces at the nanoscale level, such as van der Waals forces, can be measured experimentally. |

## Overview of Instructional Materials

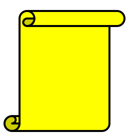
### Teacher Guides

The teacher guides contain background information, suggested procedures, instructional strategies, guiding questions, and connections to previous and subsequent lessons. The teacher guides are formatted in a landscape view. This allows the teacher to correlate between the teacher guide, the PowerPoint slide, and student journal. Each lesson contains the student objectives, a preview of highlights—"At a Glance for the Teacher", vocabulary, estimated teaching time, materials for activities, demonstrations, and Web site URL addresses. The text of the guide is structured such that background information and pedagogy are in italics and suggested teacher script is in bold. Some questions from the student journal are embedded in the script and are underlined to note formative assessment checkpoints to check for students' understanding of lesson objectives. These questions are mapped to the student learning objectives.

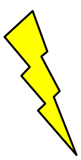
Additionally, the teacher guides use icons to draw attention to specific items.



Important: A star notes special content or pedagogy that can significantly enhance student understanding based on pilot-teacher input.



Vocabulary: A scroll notes vocabulary terms. Please see the end of each lesson in the teacher guide for definitions.



Time Savers: A lightning bolt notes a suggestion for a time saver. If you are running short on time, use these suggestions to optimize your time.

### Student PowerPoint Slides

This module uses PowerPoint slides to guide instruction. In addition to the slides that frame the lesson's content, additional slides for each lesson include a flowchart so that students can be reminded of previous lessons as well as a slide entitled "Making Connections." The "Making Connections" slides include questions that assist teachers in formatively assessing student understanding.

### Student Journals

The student journal functions as an archive of the students' written response to activities, probing questions, graphing, and diagramming. Therefore, students will find their journals useful as study guides. It is suggested that the teacher regularly collect the student journal for formative assessment and for grading. Some questions are underlined to note formative assessment checkpoints to check for students' understanding of lesson objectives.

**Direct Vocabulary Instruction Strategy**

When introducing new vocabulary to students, teachers can help students learn the meaning by following the steps below.

1. Present learners with a brief explanation or description of a new term. For example: "Adhesive: A substance that can stick to another object."

2. Then, present learners with a nonlinguistic representation of the new term or phrase. This could be a drawing, an artifact, or even acting out the meaning of a word.

3. Ask learners to generate their own verbal description of "adhesive."

4. Ask learners to create their own nonlinguistic representation of "adhesive."

5. Periodically ask learners to review the accuracy of their explanations and representations.

Adopted from: Marzano, R. J., Pickering, D. J., & Pollock, J. E. (2001). *Classroom instruction that works: Research-based strategies for increasing student achievement.* Alexandria, VA: Association for Supervision and Curriculum Development.

**Resources for Definitions**

The module's definitions are adopted/adapted from one or more of the following sources:

Bellairs, A. (1970). *The life of reptiles.* Universe Books: New York, NY.

Mathematics in Nanoscale Science and Engineering. (2002). Institute for Pure and Applied Mathematics. Retrieved August 23, 2006, from **www.ipam.ucla.edu/programs/nano2002/**

Merriam-Webster OnLine. (2006). Retrieved August 23, 2006, from **http://www.m-w.com/**

Oxford English Dictionary: OED OnLine. (2006). Retrieved August 23, 2006, from **http://www.oed.com**

Ramig, J.E., Bailer, J., & Ramsey, J. M. (1995). *Teaching science process skills*. Good Apple: Torrance, CA.

Ratner, M. & Ratner, D. (2003). *NanoTechnology: A gentle introduction to the next big idea.* Pearson Education, Inc.: New Jersey.

| **Big Ideas in Nanoscale Science** | **Essential Understandings** |
|---|---|
| Fundamental Concepts and Principles | Students will understand: |
| **Properties of Matter**<br>Surface interactions can dominate and changes in properties can arise at the nanoscale. | 1. Electrical and magnetic forces affect properties of materials, specifically physical and mechanical.<br>2. At the nanoscale level, a large fraction of an object's atoms or molecules are exposed at its surface; therefore, the object's properties are dominated by surface interactions. |
| **Forces**<br>Electrical and magnetic forces are the most important of the fundamental forces at the nanoscale level. | 1. Fundamental forces are usually classified as being strong, weak, gravitational, and electromagnetic (electrical and magnetic). All other forces are subcategories of these classifications.<br>2. Adhesion, the attractive force between two unlike materials, is dependent upon the total area of contact between the materials' surfaces.<br>3. Adhesion mechanisms include: mechanical interlocking, interdiffusion, surface reaction, capillary action, suction, and intermolecular forces.<br>4. Intermolecular forces act at the nanoscale.<br>5. Van der Waals forces are the only attractive intermolecular forces between two non-polar, neutral objects. |
| **Energy**<br>The flow of energy in large part drives processes of change in biological and chemical systems. | 1. Energy is a fundamental quantity that every physical system possesses; it determines how much work the system can be made to do, or how much heat it can exchange. Simply put, a system's energy enables the system to produce change.<br>2. Kinetic energy is that energy associated with the motion of an object while potential energy is the stored energy associated with the relative position or configuration of the system's components and the forces between them.<br>3. Any change in the relative position or configuration of the system's components will either increase or decrease the system's potential energy. The system will strive to a position or configuration where the energy is at a minimum.<br>4. Van der Waals and other intermolecular forces result in changes in distances and configurations between surfaces at the nanoscale, leading to adhesion and a lower energy for the system. |
| **Measurement and Size**<br>Imaging and measurement tools allow for detection, characterization, and manipulation of nanostructures. | 1. Nanoscience is the study of the structure of atoms and molecules with at least one dimension roughly between 1 and 100 nanometers.<br>2. Scientific instruments can be used to characterize and measure properties of objects, their structure and surfaces, even if the objects cannot be seen.<br>3. The size of a single atom or small molecule is measured at the nanometer scale.<br>4. Magnetic and electric forces at the nanoscale level, such as van der Waals forces can be measured experimentally.<br>5. Nanoscale science, technology, and fabrication sometimes require cleanroom environments. |
| **Interdisciplinary Nature of Nanoscale Science**<br>The nature of nanoscale science, technology, and engineering is interdisciplinary. | 1. The understanding of the properties and interactions of atoms and molecules may lead to advances in biology, chemistry, and physics. |
| **Ethical and Social Issues of Nanoscale Science and Technology**<br>Social interactions can occur between scientific and engineering communities and society. | 1. It is the responsibility of scientists and practitioners to communicate information necessary for the public to make informed decisions.<br>2. A sound understanding of nanoscience can help to inform public policy. |

NanoLeap

# *Investigating Static Forces in Nature: The Mystery of the Gecko*
# Lesson 1: How Can a Gecko Walk on a Ceiling?
# Engage

**Student Learning Objectives:**

- Make observations and interpretations of how the gecko's foot interacts with surfaces
- Formulate possible adhesive methods that might be considered for further investigations

**At a Glance for the Teacher:**

- o Frayer Model: "What Are Your Ideas About Nanoscale Science?"
- o Observations of *NanoSize Me* and *Tricky Feet* videos
- o Comparison of observations and interpretations
- o Observations of gecko images

Note: Some questions from the Student Journal are underlined as formative assessment checkpoints for you to check students' understanding of lesson objectives.

**Estimated Time:** 45–60 Minutes

**Vocabulary:** Adhere, Adhesion, Interaction, Interpreting, Macroscale, Mechanism, Nanoscale, Observing, Qualitative Observing, Quantitative Observing, Surface
*Refer to the end of this Teacher Guide for definitions.*

**Materials:**

- PowerPoint for Lesson 1
- Student Journal for Lesson 1
- Videos *NanoSize Me* and *Tricky Feet* found at: http://www.mcrel.org/nanoleap/multimedia/index.asp
- Computer with LCD projector
- Multiple colors of pens or pencils (optional)
- Optional: live geckos, aquarium, and crickets for an in-class introduction one week prior to the module.

| **Slide #**<br>**Student Journal Page #** | *Teacher Background Information and Pedagogy*<br>**"Teacher Script"** |
|---|---|
| Slide 1<br>Introduction to NanoLeap<br><br>Student Journal Page: 1–1<br><br>Student Journal Page: | Students will use a Frayer Model (Student Journal) to organize their thoughts about nanoscience. The Frayer model (Frayer, Frederick, and Klausmeier, 1969) is a word categorization activity that helps learners to develop their understanding of concepts[2]. Once students have had a chance to write down their thoughts, elicit student responses and record them on the board. Listen carefully to their answers, but do not provide feedback at this time. Acknowledge students answers by saying "Thank you for the comment." While students may not have much to report at this time, they will build upon and revise their responses in future lessons using this graphic organizer. Explain to students that throughout the module, they will be building upon what they now know to a deeper understanding of nanoscale science and technology.<br>1) *Prior to showing the video, have students begin the Frayer Model by recording a definition of "Nanoscale Science" using their own words in the upper-left box.*<br>**"We will begin our journey to the Nanoworld with a video. Before we do this, let's complete the chart in which you can record what you know about nanoscale science by listing examples and non-examples."**<br><br>2) *Play the NanoSize Me video. During the video, students may record notes in the "Information" box of the Frayer Model. Video available at: http://www.mcrel.org/nanoleap/multimedia/index.asp. The purpose of the video is for student awareness of nanoscale science applications. It is not necessary for students to completely understand the content of each of the examples. However, some field test teachers recommended pausing the video and checking students' understanding by listening to student questions if time allows.*<br><br>3) *Following the NanoSize Me video, have students modify their Frayer Model responses.*<br>**"We will continue our journey to the Nanoworld with another video. In this module, we will be studying forces that are dominant at macro (visible world) and nanoscale (unseen world). The nanoscale is an extremely small scale, measurements can be made with the unit 'nanometer," which is one billionth of a meter."**<br><br>4) *Show the thirty-second video "Tricky Feet." After showing the video, begin the script and PowerPoint slide. Video available at: http://www.mcrel.org/nanoleap/multimedia/index.asp. For the purposes of assessing prior knowledge, ask the scripted question below prior to Slide 2.*<br>*Ask the students:* |

[2] Barton, M. L., & Jordan, D. L. (2001). *Teaching reading in science: A supplement to the second edition of teaching reading in the content areas teacher's manual.* Aurora, CO: Mid-continent Research for Education and Learning.

1–2

**"How do you think these animals are able to crawl on walls and ceilings?** *(Elicit student responses and have students record responses in their journal.)* **Scientists have been puzzled about this for hundreds of years, and only recently have they come up with possible explanations. Their new ideas came from measuring devices that can examine the gecko at a scale close to the size of individual atoms. That level is called nanoscale."**

Slide 2

Student Journal Page: 1–2

*5) Ask students to explain the characteristics of observations and interpretations. See explanations for each in the Characteristics of Observations and Interpretations. Have students complete the chart in their journal. Make sure students have included similar responses to those in the chart below. Provide some examples from everyday life in addition to the definition at the end of the Teacher Guide.*

**Characteristics of Observations and Interpretations—Sample Responses**

| Observations | Interpretations |
|---|---|
| Makes use of senses<br>Makes use of instrumentation (when possible)<br>Uses illustrations and labels<br>Are statements and **not** questions<br>Qualitative: Description of characteristics<br>Quantitative: Numeric or measurements | Explains how/why based on what you scientifically observe<br>May show diagrams or illustrations of how you think something works<br>Bases explanation on scientific observation, experience, or something learned earlier (extant data)<br>Are statements and **not** questions |

*6) Once the chart is completed, have the students classify the statements about the frog in their Student Journals. Emphasize the difference between qualitative and quantitative observations. Students complete the responses to the journal questions on page 1–2.* **"For the picture of the frog above, label the following as observations (O), interpretations (I), or questions (Q)."**

*Answer Key :*
*The frog is green. (O-Qualitative)*
*Why is the frog on the person's arm? (Q)*
*The frog is ready to jump. (I)*
*The frog is slimy. (I)*
*The frog has 2 eyes. (O-Quantitative)*
*The frog is hungry. (I)*

| | |
|---|---|
| Slide 3<br><br>Student Journal Page: 1–3 | *7) Have the students make observations of the gecko images.*<br>**“We are going to begin our investigation by making some observations of a gecko at the macroscale level. Write down as many observations as you can based on the images that you see on this slide. Look for similarities and differences among the images. Record your observations on the left side of the chart in your journal.”**<br><br>*Circulate around the room and assist students with questions. If students ask, state that the gecko in image 1.2 is on a vertical surface, while the geckos on images 1.1 and 1.3 are upside down on a horizontal surface. Students may have questions about the surface of image 1.3. Ask students to take a closer look at the feet on this image in order to describe the surface. This can be an interpretation listed in their journal.*<br>*Note to teacher: The gecko is adhering to glass in image 1.3.* |
| Slide 4<br><br>Student Journal Page: 1–3<br><br><br><br><br><br><br>Optional | *8) Ask the students:*<br>**“Now that you have made observations about the gecko and the surfaces, it is time to write down some interpretations of these images. Record your interpretations on the right side of the chart.”**<br>*The degree of inquiry from these observations and interpretations can be adjusted with the degree of response prompted by the teacher. If students do not describe the surface in their observations, you may want to ask them what kind of surfaces the gecko is adhering to.*<br><br>*9) Have students work in groups to make comparisons—this can be optional if you are running out of time. If so, proceed to step 10.*<br>*Optional:* **“Working in small groups, exchange and share your observations and interpretations with others in your group. Devise a system for keeping track of each other’s responses in your Student Journals. Note any similarities.”**<br><br>*Once students have had a chance to make some individual observations, allow them to gather into a small group to compare their observations. Have the students report out using white boards with two columns: Observations and Interpretations. Spend about 5–10 minutes on this sharing out.*<br><br>*Encourage students to include any new observations and interpretations made by their classmates that they themselves did not make. Provide different colored pencils or pens so that students can differentiate between their own observations and interpretations and those of their classmates. For instance, students could use one color for their own observations, and another color for their own interpretations. A third color could indicate observations made by other students, and a fourth color for others’ interpretations.* |

| | |
|---|---|
| Slides 5–6<br><br>Student Journal Page: 1–4 | *10) Allow students time to observe images. Then, begin debriefing students with the questions on Slides 5 and 6*<br><br>1. What do the images have in common?<br>*Each image has a gecko that is "sticking" or "adhering" to a surface. In the second image, the gecko is hanging on the smooth underside of a piece of transparent surface. Since the surface is clear, it may not be a direct observation; however, students might interpret this.*<br>2. What do you observe about the surfaces and textures in these images?<br>*In the field test, some students said that the surface appears to be "smooth," while others said "rough." Some field test students identified the substances as wood, plastic, or glass.*<br>3. What do you interpret about how the gecko's foot interacts with the surface?<br>4. What questions do you have or additional information do you need to know in order to understand what makes a gecko adhere to surfaces?<br>*Allow students to work in their groups to make a list of topics they would need to know more about in order to understand what is happening.*<br>**"We will be investigating many of these questions in future lessons."**<br>*Note: You may want to use the flow chart on slide 8 to show future lesson topics related to their questions.* |
| Slide 6<br><br>Student Journal Page: 1–4 | 5. What are some possible methods for the gecko to adhere to a surface?<br>*Possible answers from the pilot test include: suction cups, sticky feet, glue, sharp claws*<br>6. Describe how you made your observations in today's lesson.<br>*Observations: a. eyes, b. visible, c. gravity*<br>7. What variables affect the force between the animal and the surface?<br>*Students might state: distances apart, mass, surface-area contact, moisture, cleanliness* |
| Slide 7<br><br>Student Journal Page: 1–4 | *11) Students might have questions about the gecko in the images. If so, you may provide information similar to what is described in the script. Debrief the groups' responses by recording them on the overhead, white/chalk board, or chart paper. These should be kept for the essay assessment at the end of the module. Student responses regarding the possible methods of gecko adhesion will vary. Some may include the following: claws, suction, friction, water, secretion (glue-like substance), Velcro-like substance on the foot, or static electricity. It is all right if students don't mention all of these at this time; however, many of these have already been considered (and evaluated) by scientists.*<br><br>*At the end of each lesson, hold a short discussion with questions from the "Making Connections" slide. These questions are intended to be used by the teacher as a formative assessment and to allow students to connect key information to what was learned in previous lessons.* |

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| | **"Geckos are small reptiles found in the tropics. They are often observed in the strangest places, because they stick to just about anything. Geckos are known for their remarkable wall-climbing ability. The method for adhesion is not well established. How do you think the gecko adheres to a vertical surface or a ceiling?"**<br><br>**"Making Connections: The questions here are a chance for us to discuss what was learned during this first lesson."**<br>**1. "Describe one or two ideas that you learned during this lesson."**<br>**2. "How do you think the gecko sticks to the ceiling?"**<br>**3. "What should we explore next?"** (*If students suggest something outside the scope of the module, encourage them to try some of these ideas at home.*)<br><br>**"In the next set of lessons, we will investigate this phenomenon to better understand how the gecko adheres to a surface."** |
| Slide 8 | *12) The pilot-test teachers highly recommend using this flow chart at the end and/or beginning of each lesson. The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence. The following color code is used:*<br>*Yellow: Past Lessons*<br>*Blue: Current Lesson*<br>*Green: Next Lesson*<br>*White: Future Lessons*<br>**"In the next lesson, you will take a closer look into the role that the amount of contact between two surfaces is to better understand what is happening."** |

# Appendix: NanoLeap Physical Science Vocabulary for Lesson 1

**Adhere**
1. To hold fast or to stick
2. To bind to

**Adhesion**
1. The attraction exerted between the surfaces of objects. Can be either mechanical (e.g., suction, microinterlocking, friction) or intermolecular (e.g., electrical and magnetic)
2. Objects in contact: steady or firm attachment of objects

**Interaction**
1. Mutual or reciprocal action or influence (contact)
2. How one thing affects another

**Interpreting**
To explain or tell the meaning of

**Macroscale**
1. The length scale that is observable with the unaided eye
2. The description of objects and actions at a size visible to the unaided eyes

**Nanoscale**
1. The scale between systems of a few atoms and continuum systems
2. The description of objects and actions that occur at sizes of 1–100 nanometers (the size of a few atoms)

**Observing**
Using human senses and/or instruments to recognize, note, or describe a fact or occurrence, often involving measurement with instruments

**Qualitative Observing**
When someone describes an object or phenomenon using their own senses (e.g., seeing, hearing, smelling, touching, tasting)

**Quantitative Observing**
When someone measures an object or phenomenon using an instrument other than their own senses (e.g., ruler, scale, thermometer, etc.)

**Surface**
The exterior or boundary of an object, immediately adjacent to the air or empty space, or to another body

# *Investigating Static Forces in Nature: The Mystery of the Gecko*
# Lesson 2: What Do We Mean When We Speak About Surfaces in Contact?
# Explore

**Student Learning Objectives:**

- Compare the amount of surface contact (real contact) to total unit area (apparent contact) at the macro level
- Understand that different textures of surfaces have different contact ratios

**At a Glance for the Teacher:**

- Observe and quantify surfaces, textures, surface contact, and total surface area
- Student Activity: "Sole Impression"

<u>Note: Some questions in the Student Journal are underlined as formative assessment checkpoints for you to check students' understanding of lesson objectives.</u>

**Estimated Time:** 45–75 Minutes

**Safety Note**

Have students wear safety goggles in accordance with district safety policy.

**Vocabulary:** Area, Contact, Pressure, Ratio, Surface

*Refer to the end of this Teacher Guide for definitions.*

**Materials:**

- PowerPoint for Lesson 2
- Student Journals for Lesson 2
- Computer with LCD or overhead projector

For each group of students for student activity: *Sole Impressions*

- Tempera paint and rollers, or finely ground dark sidewalk chalk (purple or blue work best), or ground-up charcoal
- Original graph paper (not photocopied) or graph paper on goldenrod
- Tray or container to hold chalk (old baking trays, kitty litter boxes)
- Old shoes (or students' shoes that they don't mind getting dirty)

| <u>**Slide #**</u><br>**Student Journal Page #** | <u>*Teacher Background Information and Pedagogy*</u><br>**“Teacher Script”** |
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| Slide 1<br>Title | *In this lesson, students will explore how the relative amount of surface contact observed depends on the scale that one is using.*<br>*1) Review “Making Connections” questions from the PowerPoint in Lesson 1.*<br>**“In the last lesson, we made observations and interpretations about how geckos adhere to surfaces.”** Review Lesson 1 “Making Connections” questions. **“In this lesson, we will study how much contact is actually made between a shoe and a solid surface.”** |
| Slide 2<br><br>Student Journal Page:<br>2–1 | *2) Display slide 2:*<br>**“This first slide shows an image of three shoes taken from a distance. Indicate the relative amount of contact between each shoe and the surface. For each shoe, circle one answer and provide a reason for your answer. Why are the details difficult to observe? How is this similar to observing an object under a microscope under low power?”**<br><br>*While students may be frustrated with making observations from a distance, allow students to struggle with this first image. Some students might state that they are all in contact with the floor. Other students will say that the shoes on the left and right have about the same amount of contact with the floor, but the one in the middle would have less.*<br><br>*3) Have students respond to the questions at the bottom of their Student Journal. For the first question, students might state that this was difficult because of the view of the images is at a distance. For the second question students may suggest “getting a picture that is closer to the objects being observed.” This type of thinking will focus students about the need for closer observations and the need for instrumentation which will be discussed later.* |
| Slides<br>3–4<br><br>Student Journal Page:<br>2–2<br>2–3 | *4) Display slide 3 and 4:*<br>**“Take a closer look at the surfaces of these shoes. Indicate the relative amount of contact between each shoe and the surface. For each shoe, circle one answer and answer the questions that follow.”**<br><br>*Slide 3 shows the same side view. Slide 4 shows the bottom (sole) of each shoe. These views represent a closer, more detailed view similar to viewing smaller details of an object through an instrument. If your students don’t mention it, you might want to point out that the cleats (images 2.3 and 2.6) will penetrate into turf providing more surface contact than when walking on a hard surface such as sidewalk.* |
| Slides | *5) Display slide 5 and 6:* |

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| 5–6<br><br>Student Journal Page:<br>2–3 | **"These two slides show a method for determining the ratio of contact area of a shoe to the total surface area that is walked upon."**<br>*6) Lead students through the Student Activity "Sole Impression." Allow students to determine the ratio of the contact area of their shoe to the total area. Using something like finely ground sidewalk chalk, charcoal, or tempera paint, have students make an imprint of a shoe's sole on a sheet of graph paper. See Student Journal. Students can then compare the ratio of contact area to total area of shoes typically worn by students in class.*<br>*7) Field test teachers noted that some students with the same type of shoe had different ratios of contact area to total area. Use this as an opportunity to discuss the reasons for these differences. The discussion might include differences in the amount of chalk/paint applied to the shoe, differences in the amount of pressure of the shoe to the paper, or inconsistencies in counting squares or variations in the methods used.*<br>*8) Allow students to speculate about the advantages of high ratio vs. a low ratio (a high ratio should provide better traction when playing on a slippery surface, a low ratio is helpful when one is interested in sliding such as when skating). What are circumstances when each is desired? As extensions, students could design and test their own related questions.*<br><br>*Pilot teachers time-saver suggestions:*<br>*Students can use the "count-the-squares" method to determine the amount of contact area. When using this method, students will need to determine what counts as a covered square. One method might be to count all squares that are half covered or more, and not count them if are less than half covered. Students can count intersections; there is less uncertainty about whether to count them.*<br><br>*Teach students to count squares by using large blocks of squares instead of individual squares.* |
| Slide 7<br><br>Student Journal:<br>Pages:<br>2–4<br>2–5 | *9) Display slide 7. Solicit from the students the differences they can note between the images. Draw out from them the idea of surface contact (real contact) to total unit area (apparent contact).*<br>**"This slide shows two images at different scales. The image at left shows a shoe that appears to have a large percent of contact between the sole and the floor. The diagram at right illustrates that two hard surfaces (like the shoe and the floor) actually have less actual contact when observed up close. Based on your examination of different shoe soles, what are your ideas about the surface of a gecko's foot, and what makes you think that way?"** |
| Slide 8 | *10) Ask students to answer the "Making Connections" questions as a discussion or in their journals. Draw their attention to question 2. Prompt students to think about what would happen if a heavy person were wearing the shoes verses a lightweight person. Students might also suggest the variable of hard sole vs. deformable shoes, or hard floors vs. carpeted.* |
| Slide 9 | *11) The pilot-test teachers highly recommend using this flow chart at the end and/or beginning of each lesson. The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence. The following color code is used:* |

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| | *Yellow: Past Lessons*<br>*Blue: Current Lesson*<br>*Green: Next Lesson*<br>*White: Future Lessons* |

# Appendix: NanoLeap Physical Science Vocabulary for Lesson 2

**Area**
1. A part of the surface of an object
2. The amount of space of a two-dimensional object (length times width for a rectangle)

**Contact (macroscopic)**
1. The union or junction of surfaces
2. The state or condition of touching: the mutual relation of two bodies whose external surfaces touch each other

**Force**
A push or a pull that acts on an object

**Ratio**
The relative quantities, amounts, or sizes of two things. It is usually expressed by dividing the first quantity by the second, or the fraction or quotient expressing this.

**Surface**
The exterior or boundary of an object, immediately adjacent to the air or empty space, or to another body

NanoLeap

# *Investigating Static Forces in Nature: The Mystery of the Gecko*
# Lesson 3: What Are Your Ideas About Small Sizes?
# Explore/Explain

## Student Learning Objectives:

- Classify and compare objects in different size ranges to have a better understanding of the nanoscale
- Understand relative size of objects at different scales
- Describe nanotechnology, some of its applications, and the positive as well as negative this technology to someone who is not familiar with the subject

## At a Glance for Teachers:

- Comparisons of objects that range from the meter scale to the picometer scale
- Familiarization of small-scale objects
- *Nanoscale Me* interactive
- Powers of Ten Web sites
- Update Frayer Model
- Homework: *What is Nanotechnology?* Select reading on nanoscale science and technology, essay response to readings

Note: Some questions in the Student Journal are underlined as formative assessment checkpoints for you to check students' understanding of lesson objectives.

**Estimated Time:** Two 45-minute class periods.
Essay assessment approximately two additional hours to complete as homework

**Vocabulary:** Macroscale, Micrometer, Millimeter, Nanometer, Nanoparticle, Nanoscale, Nanotechnology
*Refer to the end of this Teacher Guide for definitions.*

**Teacher Resource**

In June 2006, *National Geographic* published an article entitled "Nano's Big Future" by Jennifer Kahn. Reading this article can offer you and your students additional insights into the life-changing impact of nanotechnology so that you can assist your students with the essay writing assignment.

For a preview of the article, go to: http://www7.nationalgeographic.com/ngm/0606/feature

objects at

impacts of

**Web sites**

The following resources can help students develop a perspective of the nanoscale in relation to other known scales:
http://www.mcrel.org/nanoleap/multimedia/Nanosize_me.swf

http://www.nanoreisen.de/

http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/

http://microcosm.web.cern.ch/microcosm/p10/english/welcome.html

**Nanoscale Background:**
The activity in this lesson guides students as they begin to think about size and scale from macro to micro to nano. It builds on research by Tom Tretter[3] and his colleagues on the different ways that people understand and classify objects of different sizes. This research noted that students need to mentally manipulate new units, like a nanometer, in order to make sense of the numbers used during a comparison. In addition, Tretter discovered that high school students had difficulty ranking microscopic objects compared with gifted students or experts, who distinguished small-sized objects by grouping them into distinct landmarks such as small macroscopic items, microscopic, many atoms (nanoscale), and the size of an atom. This activity will provide students with an opportunity to use new landmarks as they compare images of very small objects.

**Materials:**
- PowerPoint for Lesson 3
- Student Journals for Lesson 3
- Computer with LCD or overhead projector
- Make arrangements for students to have access to the computer lab

**Nanoscale Activity:**
- Student Data Sheet
- *Nanoscale Me* interactive http://www.mcrel.org/nanoleap/multimedia/Nanosize_me.swf
- Optional Student Graph
- **Readings and Web sites for student essay responses:**
  - *National Geographic* article about nanotechnology entitled "Nano's Big Future." By Jennifer Kahn. http://www7.nationalgeographic.com/ngm/0606/feature4/index.html **(also included on CD)**
  - Other resources and Web sites found in the Student Journal, 3–7 and 3–8.

**Prepare Computers**
Prepare links to above Web sites. Make sure Flash Player application is installed on each computer. If it is not currently on the computers, they may be downloaded from: http://www.adobe.com/shockwave/download/download.cgi?P1_Prod_Version=ShockwaveFlash&promoid=BIOW

**For Homework: Essay Assessment**
- *What Is Nanotechnology?* Explanation of essay assessment (Note: These are the last 4 pages of the Student Journal for Lesson 3)
- For the instructor: Anchor Papers for Essay Assessment (See Appendix A of this Teacher Guide)

[3] Tretter, T. R., Jones, M. G., Andre, T., Negishi, A., & Minogue, J. (2006). Conceptual boundaries and distances: Students' and experts' concepts of the scale of scientific phenomena. *Journal of Research in Science Teaching* 43(3). 282-319.

| **Slide #**<br>**Student Journal Page #** | *Teacher Background Information and Pedagogy*<br>**"Teacher Script"** |
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| Slide 1<br>Title<br><br>Slide 2<br>Student Journal Page:<br>1–1 | 1) *Display Slide 2 of the Frayer Model template:* Your Thoughts About Nanoscale Science and Technology<br>**"Remember this chart from Lesson 1? You will be revisiting this chart at the conclusion of this lesson so that you can add anything new you've learned."** |
| Slide 3<br><br>Student Journal Page:<br>3–1 | *According to the National Nanotechnology Initiative, nanotechnology includes the science, engineering, and technology related to the understanding and control of matter at the length scale of approximately 1–100 nanometers.*<br>2) *Display Slide 3.*<br>**"In nanoscale science, objects and phenomena are studied on a much smaller scale than we can see with our eyes. In this slide, familiar objects are divided into ten equal parts or one hundred equal parts. The resulting measurements are used to provide an example of a metric prefix from centimeter through nanometer. *Nano* is a Greek word for 'dwarf.' In modern times, it is used as a prefix to note one-billionth of a meter, $10^{-9}$ meters, or 1 nanometer (nm). One nm is about 14 hydrogen atoms long. Nano can be used with other measurements. A nanosecond, for example, is a billionth of a second. Have you heard the prefix nano used anyplace else? In popular culture, it may not always mean a billionth (e.g., Nano iPod)."** |
| Slide 4 | 3) *Display slide 4. Explain to students how the prefixes on this slide are related to those in which students are already familiar. You may want to have them define the prefixes that they have learned previously using the base unit for length, a meter.*<br>**"This slide shows the metric prefixes and definitions in relation to a meter from "milli" through "pico."**<br><br>*Optional: Use this slide as a poster that is kept in the room for future reference.* |
| Slide 5<br>Student Journal Page 3–1<br><br>Computer Lab | 4) *Display Slide 5: What Are Your Ideas About Small Sizes? Assess student' prior knowledge about small objects. Typically you will find that students can easily sort objects into those that are visible and those that are invisible to the unaided eye.*<br>**"Open the NanoScale Me interactive using the URL in your Student Journal. On the size line on Student Journal page 3–1, you may mouse over the images of objects and the name will appear. Circle the objects** |

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| | **that are smaller than a penny. Underline which of those objects would be considered microscopic (unable to be seen with the unaided eye).”** |
| Slide 6<br><br>Student Journal Page<br>3–4<br>3–5 | *5) Explain that in this activity, students will have some new experiences in classifying and ordering very small objects to better understand the size of objects in the nanoscale. Begin by having students review metric prefixes and define a nanometer by thinking about objects that can be divided into equal parts.*<br>**“You are going on a journey into a new world through the use of imagery and artists’ animation. As you begin this journey, it will be important to understand some metric prefixes in order to navigate into this world. On the bottom of Student Journal 3–1, common objects are ranked from largest (one centimeter) to smallest (one nanometer). Compare the size of each object by reading the labels for each image.”** |
| Student Journal: Data Sheet/Student Responses: Pages:<br>3–2<br>3–3<br>3–4 | *In the NanoSize M*e *interactive, students will be conducting five image sorts using an online interactive. The progression of the sort is increasingly smaller.*<br><br>*6) Model the use of the NanoScale Me interactive by providing a demonstration of the “Sort Meters” activity. (Access the activity through the navigation bar located at the bottom of the interactive screen.) Do this in conjunction with the Student Journal page 3–2 for the meter sort. Ask students to write their prediction in their journal (left column) before they sort with the interactive. Then, in the right column, they should record the actual order. There should be little disagreement on the objects order because students are familiar with this range.*<br>**“In the interactive, click on “Sort Meters.” Move your mouse over the objects in order to determine their names. Note that the objects are not depicted in the same scale. In your journal, page 3–2, first record your predicted order largest to smallest based on the width of the object. Then see how well you did by completing the image sort in the interactive and recording the actual size orders.**<br><br>**At the bottom of each screen is an instrument commonly used to study the objects at each range. Also the dominant force that acts on each object is listed. Simply record this information in your journal. We will be studying these ideas in more detail in future lessons.”**<br><br>*7) Working in small groups, have the students proceed to “Sort Millimeter.” Have them write their prediction in their journal (left column) before they sort with the interactive and then record the actual order on the right column.*<br><br>*Repeat this process for the remaining ranges to sort.*<br><br>*8) When students have completed each range sort, have them compare the widths of each object at the same scale by using the “Exploring Scale” page. Then, complete the “Sort All.”*<br>**“When you have completed all of the image sorts for each range, select the “Exploring Scale” link and view the images from largest to smallest. This time you can compare the relative size of each object.”** |

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| | 9) *Once students have completed "Exploring Scale," ask them a question similar to the following:*<br>**"How did this interactive change the way you compare objects at different scales? Think about how you can use this to help solve the mystery of the gecko."** (*Students may comment that they did not know there were so many degrees of objects that were so small. This may prompt students to inquire about the surfaces of the geckos foot and a ceiling at a much smaller scale.*)<br><br>10) *Revisit the "Sort All" tool to assess student understanding of the landmark images of the various ranges*. |
| Slide 7<br><br>Student Journal Pages:<br>3–4<br>3–5 | 11) *Display Slide 7. This is a whole class discussion in response to the questions on the slide. Allow each group to answer the questions in their Student Journals before sharing their responses with the rest of the class. Explain that it is difficult to tell the size of objects from many of the images we see because they look about the same size in the pictures. Use the "Exploring Scale" tool to assist students with question c.*<br><br>a. Which of the image sort ranges was the easiest to rank? Why?<br>b. Which range was the most difficult? Why?<br>c. Circle the largest in each of the following pairs:<br>Ant — Grain of Sand or Salt *(Ant)*<br>Virus — White Blood Cell *(White Blood Cell)*<br>Virus — DNA Molecule *(Virus)*<br>Atom — DNA Molecule *(DNA Molecule)*<br>d. <u>How do nanoparticles compare with cells in size</u>? *(Nanoparticles are smaller than cells.)*<br>e. <u>How do nanoparticles compare with atoms in size?"</u> *(Nanoparticles are larger than atoms.)*<br><br>*Some students will think that nanoparticles are smaller than atoms. Emphasize that all nanoparticles are made of atoms. Make reference to Slides 3 and 4.* |
| Slide 8 | 12) *If time allows, go to procedure step 14 to have the students extend their explorations at the nanoscale either in class or for homework. Then, return to this step to complete the lesson. Display slide 8 and review Making Connections:*<br>**"Making Connections: The questions here are a chance for us to discuss what was learned during this lesson."**<br>• **"How has your thinking about small sizes changed after completing the computer activity?"** *(Students should explain that their thinking has changed in that there are many ranges of different small-sized objects.)*<br>• **"Are the instruments that are used for each of these size ranges the same? Explain."** *(No. Students should be aware that there are special tools to detect objects at very small ranges.)*<br>• **"What should we explore next?"** *(Answers will vary.)* |

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| Student Journal<br>Page:<br>1–1 | *13) Prompt students to return to the Frayer Model on page 1–1 in their journals.*<br>**“Return once again to the graphic organizer on page 1–1. Make additions or revisions based on what you learned in this lesson.”** |
| Student Journal<br>Page:<br>3–5<br>Optional | *14) Use the journal questions to provide structure to students’ interactions with the Web sites listed below. This optional activity allows students to elaborate on their exploration of nanoscale using Web resources. You may also do this activity as a whole class with the teacher leading the navigation.*<br>*Web sites for Powers of Ten activity in Student Journal:*<br>http://www.nanoreisen.de/<br>http://microcosm.web.cern.ch/microcosm/p10/english/welcome.html<br><br>**“Complete the Powers of Ten activity on page 3–6 of your Student Journal. Use the Web sites to explore the world of small sizes. Focus your attention on smaller objects rather than larger objects. Complete questions in your journal that pertain to the appropriate Web site.”** |
| Homework:<br>Essay<br>Assessment—<br>*What Is Nanotechnology?*<br>Writing Prompt<br><br>Student Journal<br>Pages:<br>3–7<br>3–8 | *15) In this formative performance assessment, students will demonstrate their learning by responding to the following writing prompt.*<br><br>Explain the term “nanotechnology” to someone who has heard of it only on T.V. Then, explain how scientists and the general public should react to the latest research and applications in nanotechnology.<br>• Define Nanotechnology.<br>• Give examples of specific nanoapplications to help illustrate nanotechnology. These should come from the Internet resources you read as well as from what you have learned in this unit.<br>• Describe nanotechnology’s impact on science and how the application involves research from many different science subjects (e.g., biology, chemistry, physics, engineering).<br>• Explain why it is important for scientists to discuss the technology’s positive and negative impacts with each other and with the general public.<br>• Include an explanation for why the general public should stay informed about the progress of nanotechnology.<br><br>*Students will draft their written responses as homework and then participate in a peer-review activity during class time. Incorporating peer review transforms the “assessment” into a writing-to-learn opportunity that engages students in critical thinking with a more in-depth exploration of the content. Since students will likely focus on a range of nanoapplications, the peer-review process enables students to increase their awareness of the various possibilities for nanotechnology. Furthermore, feedback received through the peer-review process will help students to refine their writing before the final* |

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| | *essays are submitted. Through this process, students will also become very familiar with the scoring rubric and expectations for the writing, thereby encouraging them take responsibility for evaluating their own work. Subsequently, the teacher's paper load in this module can be minimized; you may only need to intervene and evaluate the writing when there is a large discrepancy among peer reviews.* |
| Slide 9<br>Introducing the Assessment<br><br>Student Journal Pages<br>3–6<br>3–7<br>3–8<br>3–9<br><br>June 2006, *National Geographic* published an article entitled "Nano's Big Future" by Jennifer Kahn | *16) Display the "Nanotechnology: Life Changing?" slide of the PowerPoint presentation and read aloud the following two quotes:*<br>**"Nanoscience and technology will change the nature of almost every human-made object in the 21st century."**<br>**–M.C. Roco, R. S. Williams, & P. Alivisatos, 1999**<br><br>**"The government and funding agencies have recognized that the societal and ethical implications of this new field must be explored right alongside research in the lab."**<br>**–Kristen Kulinowski, Executive Director**<br>**Rice University's Center for Biological and Environmental Nanotechnology**<br><br>*17) Explain to students that while many people have heard of "nanotechnology," few could explain exactly what it is or why it may have "life-changing" effects. The homework assignment for the week will be to spend some time reading about current nanoapplications and carefully consider both the positive and negative impacts of this new technology. Then, students will write an explanation of nanotechnology, provide one or more examples of how this technology can be used, and describe the benefits and potential drawbacks to someone who is not familiar with nanotechnology.*<br><br>*18) Instruct students to turn to the Essay Assessment: What Is Nanotechnology? section of their Lesson 3 Student Journal (pages 3–7through 3–10). Explain to students that they will write a brief essay that demonstrates what they have learned in the module so far as well as from reading several select articles.*<br><br>*19) Review the prompt to ensure students understand the writing assignment. The bulleted list provides scaffolding to assist students in fully addressing the prompt. Written responses should not exceed one typed page (or one handwritten page front/back).*<br><br>*20) Review the instructional rubric that will be used to assess the written response. The more familiar students are with the expectations of the assessment, the more responsibility they can assume for their own work.*<br><br>*21) The National Geographic article can be used by students to respond to the essay writing prompt. The pilot teachers indicated that the National Geographic article presented reading challenges for some students. Therefore, we included a list of Internet-based resources that students can use as alternatives. If you choose the Internet-based resources,* |

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| | *decide whether to assign students specific articles to read or to allow them the freedom to choose those that most interest them. Note: The list of resources capture a range of reading levels. The texts offered by the Center for Responsible Nanotechnology are suitable for a high-school reading level. Those from Science News for Kids and Nanooze are less challenging.*<br><br>22) *To facilitate active reading and to assist in preparing their essays, students will use the SQ3R (Survey, Question, Read, Recite, Review) strategy (Robinson, 1961 as cited in Billmeyer & Barton, 2002). Pages 3–9 through 3–10 of the Student Journal provides guidance in using this reading strategy. If students are not familiar with SQ3R, it may be helpful to model the process for them. Students should plan to spend one hour at home reading the National Geographic article or their selected resources and completing the SQ3R strategy.* |
| Drafting the Essay | 23) *Invite students to refer to their journals to help them plan their responses. While the assessment is "Open Journal/Notes," emphasize to students that their essay responses should not simply repeat journal responses or language from the articles they read. The journals are intended to help students recall their learning experience. The writing should be in students' own words and reflect a sophisticated understanding of the content.*<br><br>24) *Instruct students to refer to the rubric as they draft their written responses.*<br><br>25) *It should take students an additional hour of homework to write their essay. Explain to students that they should be prepared to share their essays in class the next time you meet.* |
| Classroom Presentations and Peer Reviews<br><br>Student Journal Page 3–9 | 26) *Explain to students that rather than a formal peer review, students will share their work in small groups of four students.*<br><br>27) *Each member of the group of four should have a rubric.*<br><br>28) *During this informal peer review, students should share aloud the results of their SQ3R and/or their draft essays. Other members of the group should provide feedback to the student who is presenting either in written form or orally. Students can then use this information to refine their essays.*<br><br>29) *Allow about five minutes for each person to share out for a total of about 20 minutes for this review process.* |
| Refining and Evaluating the Final Essays | 30) *Encourage students to revise and polish their writing according to the feedback they received. Assign a due date for completing their final draft.*<br><br>31) *On the due date, collect the rough and final drafts from each student.*<br><br>32) *Refer to the Anchor Papers for Essay Assessment to assist in evaluating the final essays (available in the Appendix A* |

| | | |
|---|---|---|
| | | *section of this guide). The instructional rubric is found on page 3–11 of the Teacher Guide.* |
| Slide 10 | *33)* | *Make sure students update their graphic organizers in their student journal (page 1–1) with new information learned from this assignment.* |
| Slide 11 | *34)* | *The pilot-test teachers highly recommend using this flow chart at the end and/or beginning of each lesson. The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence. The following color code is used:*<br>*Yellow: Past Lessons*<br>*Blue: Current Lesson*<br>*Green: Next Lesson*<br>*White: Future Lessons* |

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# Appendix A: Anchor Papers for *What Is Nanotechnology?* Essay

**Purpose:**
The anchor papers can assist you in using the rubric to score students' culminating essays. Please refer to the rubric as you read through the various anchor papers.

**Writing Prompt:**

Explain the term "nanotechnology" to someone who has heard of it only on T.V. Then, explain how scientists and the general public should react to the latest research and applications in nanotechnology.

- Define Nanotechnology.
- Give examples of specific nanoapplications to help illustrate nanotechnology. These should come from the article you read as well as from what you have learned in this unit.
- Describe nanotechnology's impact on science and how the application involves research from many different science areas (e.g., biology, chemistry, physics, engineering).
- Explain why it is important for scientists to discuss the technology's positive and negative impacts with each other and with the general public.
- Include an explanation for why the general public should stay informed about the progress of nanotechnology.

# Instructional Rubric for Essay Assessment

| Criteria | Advanced (4) | Proficient (3) | Partially Proficient (2) | Novice (1) |
|---|---|---|---|---|
| **Writing Style and Mechanics** | • **Concise, clear, and engaging explanations** with **flawless** spelling, punctuation, and grammar. | • **Concise and clear** explanations with **minor errors** that do not interfere with communication. | • **Appropriate writing** format.<br>• Writer does **not appear to have carefully proofread**. | • **Demonstrates little or no attention** to the writing format.<br>• Has great difficulty communicating. |
| **Understanding of Content** | • Explanations about the impact of nanotechnology applications on science and society **are complete* and insightful.**<br>• **Gives detailed examples to help explain points.**<br>• Writes in **own words.**<br><br>*Responses include answers to all five bullet points in the prompt. | • Explanations about the impact of nanotechnology applications on science and society **are complete* and reasonable.**<br>• **Gives examples to make points. Could be more detailed.**<br>• Writes in **own words.**<br><br>*Responses include answers to all five bullet points in the prompt. | • Explanations about the impact of nanotechnology applications on science and society **are obvious.**<br>• Does **not always write in own words**. | • Explanations about the impact of nanotechnology applications on science and society **are irrelevant.**<br>• Copies from the article. |

## 4

You now see the word “nano” everywhere like the nano iPod, but the word nano has a more specific meaning in science. First, the word nano is Greek for “dwarf.” It is one billionth of a meter, a comma such as this one is about half a million nanometers. In addition, a nanometer is to an inch the same as an inch is to 400 miles. That is very small! The naked eye cannot see this, not even a regular microscope can. That is why scientists use what is called the AFM (Atomic Force Microscope) to see and work with things that small.

So, in nanotechnology you are studying things that are very small. For example, we didn’t understand why a gecko could stick on a wall. Well, with a special microscope, scientists saw that geckos have about one million hair-like seta on their feet. The gecko can stick to the ceiling because their tiny spatulas get into the bumps on the surface of the surface. Even if the surfaces looks flat at nano level, it is full of bumps resembling small hills. The spatulas fit into the small hills. The molecules at this level are positively, negatively, or neutrally charged. The positives are attracted to the negatives and the neutrals. The negatives are attracted to the positives and the neutrals. This generates a very tiny force, but lots of the little forces create a lot of force for the gecko to stick on anything.

In another example, there is the carbon nanotubes. Scientists have been able to take carbon atoms and arrange them to make a tube. They are 50 to 100 times stronger than steel and 1/6 the weight, and great conductors of electricity. Currently, nanotubes have been used to make sporting equipment stronger. But, since they conduct electricity better than copper and aluminum, they could possibly be used to create more efficient electrical wires. So, they could help solve the world’s energy problem. But, we are not there yet, because the carbon nanotubes break.

So, you see in both examples different sciences have to work together. With the gecko, biology works with physics. With the carbon nano-tubes and electricity, chemists need to know electricity.

The impact nanotechnology is having on science and the world is tremendous. It has the potential to help us with so many things. Some examples are, scientists can engineer many new materials like plastic that reacts to electricity, coatings that prevent rusting on iron, or clean up pollutants in water! A “new plastic” will be everywhere, in our clothes we wear, the cars we drive, the tools we use in surgery, mainly the things we use in our everyday lives. So we and the government need to stay informed because there is so much potential to solve problems that we haven’t figured out totally.

But, it is important for scientists to discuss these things with other scientists, because other scientists may be able to improve what the scientists have done. Also, we need to stay informed as well as the government. Why? Because nano particles can also be harmful very fast. In one example, small amounts of bucky balls (balls of carbon) were exposed to some cells and the cells died. So, maybe exposure could cause cancer and be toxic. Bucky balls can be made less toxic, but more research needs to be done! But, because people are so excited about the positive aspects of nano technology, scientists do not often really study the negative. We all need to stay informed and we need more research.

---

**3**

You now see the word nano everywhere like the nano iPod, but the word nano has a more specific meaning in science. A nano is one billionth of a meter. It is very small! The naked eye cannot see this, not even a regular microscope can.

For example, we didn't understand why a gecko could stick on a wall. Well, with a special microscope, scientists saw that geckos have about one million hair-like seta on their feet. This generates a very tiny force, but lots of the little forces create a lot of force for the gecko to stick on anything.

Another example is using nanotubes. They can be engineered to be light weights, strong sporting equipments, and energy efficient power lines across the country which could boost energy amazingly high. The negatives are that scientists finally conduct the right nantotube and create a world of amazingly high electrical energy, people think that if Mother Nature allows it, nano-tubes could restring the electrical power grid of the world and create too much energy. But facts are scientists don't have the right type of carbon nanotubes and aren't able to construct the bottom up assembly of the nanotubes. Many different sciences have to work together to try to understand all of these things.

It is important to discuss the positive and negative impacts of nanotubes with each other and the general public because it could create a world wide energy source and that's important. It's good to know that buckyballs can be made into an efficient composition which we can use for many things. But, people need to know how the carbon nanotube work and how they produce energy so we don't end up with an overload of electrical energy in the future.

Because they are so small, It is not good to keep it secret, because in case they made a mistake, then other scientist won't be able to fix it and it could affect the lives of the all the people on earth.

**2**

Nano allows us to see things at the nanoscale level which is much smaller. In the gecko we could see how they look like small ridges but are made of very small feet. In the National Geographic article it brings up many things nanotechnology can be used for. The application that affected me the most is Glowing Potential. We could find a cure for cancer in Nano. Discovering this would have a huge impact on science. Scientists have worked hard for many years. Being able to see things at a smaller rate helps us learn more about how atoms and molecules behave at the nano level. This would have a very positive affect on society. It would be saving lives and keeping loved ones with their families. The negative affects of this are still being explored. It is very important for scientists for share and discuss their findings. They need to share them with each other so that they can check the findings to make sure no one missed anything vital. They need to share them with the public because if they have negative side affects they could be endangering lives.

# Appendix B: NanoLeap Physical Science Vocabulary for Lesson 3

**Macroscale**
1. The length scale that is observable with the unaided eye
2. The description of objects and actions at a size visible to the unaided eyes

**Micrometer**
One-millionth ($10^{-6}$) of a meter

**Millimeter**
One-thousandth ($10^{-3}$) of a meter

**Nanometer**
One-billionth ($10^{-9}$) of a meter

**Nanoparticle**
A solid particle, 2–100 nm in size, that usually contains between 10 and 70,000 atoms, ions, or small molecules

**Nanoscale**
1. The scale between systems of a few atoms and small sized molecules
2. The description of objects and actions that occur at sizes of 1–100 nanometers (the size of a few atoms)

**Nanotechnology**
Manipulating and building new materials, structures, devices, and machines at the nanoscale level

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# *Investigating Static Forces in Nature: The Mystery of the Gecko*
# Lesson 4: What Do We Learn When We Look More Closely?
# Explain/Elaborate

**Student Learning Objectives:**

- Explain how size, structure, and scale relate to surface features
- Describe the function of compliant surfaces with regard to adhesion
  (What happens when a surface of an object is applied to the surface of another object?)

**At a Glance for Teachers:**

- Mini-Me Activity (optional)
- Visualization and diagramming of surface of gecko foot at various scales

Note: Some questions in the Student Journal are underlined as formative assessment checkpoints for you to check students' understanding of lesson objectives.

## Estimated Time: 45 Minutes

## Vocabulary: Adhesive, Compliant, Lamella, Seta, Spatula, Surface Terrain, Topography

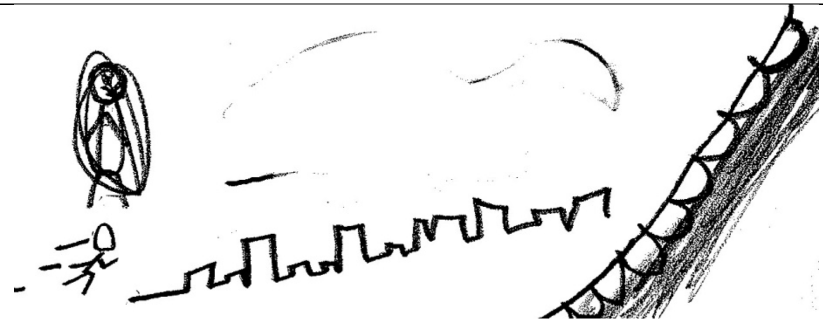
*Refer to the end of this Teacher Guide for definitions.*

**Materials**

- PowerPoint for Lesson 4
- Student Journals for Lesson 4
- Computer with LCD or overhead projector
- Transparent tape
- Pipe cleaners (for Mini-Me optional activity)
- Measuring tape (for Mini-Me optional activity)
- Modeling clay (for Mini-Me optional activity)

| **Slide #**<br>**Student Journal Page #** | *Teacher Background Information and Pedagogy*<br>**"Teacher Script"** |
|---|---|
| Slides 1& 2<br><br>Student Journal Page:<br>4–1 | ***Teacher Background:***<br>*By definition, an* **adhesive** *is any material that will be useful in holding two objects together solely by surface contact. For an adhesive to achieve extremely close contact with an object, it must have the properties of a liquid, which makes it capable of coming into intimate contact with the surface. In use, an adhesive must be able to resist any applied force that attempts to break the bond formed between it and the object or surface to which it was applied. In other words, it will need the properties of a solid.*<br>*Adapted from Johnston, J. (2003). Pressure sensitive adhesive tapes. Pressure Sensitive Tape Council. Northbrook, Illinois, Page 23.*<br>*1) Provide each student with a piece of transparent tape.*<br>**"Observe the transparent tape on a smooth surface, like a desk. Place the tape on the surface and "rub" out as many of the bubbles as possible. Use a pen to circle the bubbles on the tape. Place the actual tape onto the journal page 4–1 with the bubbles marked."** |
| Slide 3<br><br>Student Journal Page:<br>4–1 | *2) Based on student observations and this text, ask students questions similar to these below. Solicit from the students their ideas about the properties of the tape. Draw out the properties of solids and liquids and explanations for what makes the tape work.*<br>**"Would you consider the tape stuck to a surface to be an adhesive? Why or why not?"**<br>**"Work in your small groups to describe how transparent tape has the properties of both a liquid and a solid."** |
| Slide 4 | *3) Ask the students the following:*<br>**"Recall the activity we did with the shoes. What forces exist between each pair of surfaces?"**<br>○ **"Tape and smooth surface"**<br>○ **"Shoe and floor"**<br>*Students might say "adhesive force" for the tape and "gravity" for the shoe.*<br><br>**"Which surface to surface interaction do you think is most similar to a gecko climbing a wall? Explain your answer."**<br>*Allow students to explain their response.*<br><br>*4) Note to teacher: For image 4.3, point out that two compliant surfaces would come into even closer contact than one* |

| | |
|---|---|
| | *compliant surface with a hard surface.* |
| Slide 5 | *5) The Gecko Up-Close Activity: A gecko can "stick" or adhere to just about any surface from a single toe. Ask the students to make predictions.*<br>**"We are going to be making some close-up observations of the surface of the gecko's foot. Before we take a closer look, predict what you think the surface of the gecko's foot looks like at the nanoscale level."** *Solicit student predictions without comment.*<br><br>**"Let's take a closer look at the foot of a gecko. Each of the following images takes a progressively closer look at the foot of a gecko."** |
| Slide 6<br><br>Student Journal Pages:<br>4–2<br>4–3<br>4–4<br>4–5 | *Teacher Background Information: The following description of the anatomy of a gecko's toe is adapted from "The Life of Reptiles Volume I" by Angus Bellairs:*<br>*Each toe pad is covered on its under surface by rows of wide scales called lamellae, which overlap each other at their edges. Each lamella is covered by fine projecting hairs or setae about 100 microns in length. The setae branch and sub-branch several times, the final twigs ending in a pair of minute flattened tips called spatulas. It has been estimated that the total number of setae on all the lemellae of all the toes of the four feet of a gecko is about one million. Each seta carries between 100 and 1,000 spatulas on its branches.*<br><br>*Optional Hands-On Activity: Use the Mini-Me activity located at the end of this teacher guide (courtesy of the University of Wisconsin, Madison) to provide students with the experience of picturing themselves much smaller than what they are and then sculpting an image that symbolizes their understanding of the invisible world. Once students have built their mini-me, have them proceed to the student journal page 4-2.*<br><br>*6) Working in pairs, students should respond to the journal prompts and visualize what it would be like to shrink down to these scales and interact with the various structures. Tell them to be creative with their drawings, but also to be as accurate as they can when they "enter" this new world. Provide an example of the first sketch on the board. Students may describe the "view" as appearing like hills and valleys. Below is a sample student drawing depicting the centimeter scale from the field test.* |



*Optional: You may want to add some discussion about what makes a good scientific drawing.*

*7) Use the slides at the end of the PowerPoint of this lesson to illustrate a field test student's for each magnification.*

*As you introduce the four images on this slide, you may wish to use the following descriptions and explanations:*

**Image (a):** **"The toes are lined with deep ridges."**

**Image (b):** **"At the next higher magnification, one can see that the surface looks like a rug. These yarn-like projections are called "setae." Each seta is 10 times thinner than a single hair on your head. The very end of each seta is frayed into even tinier projections."**

**Image (c):** **"At the next higher magnification, one can see that the tiny projections are actually flattened on the end."**

**Image (d):** **"These tiny objects are called "spatulas" because of their shape. Each spatula is about 100 nanometers thick. This is the upper limit of the range of what is considered nanoscale science. Nanoscale science is the study of objects in the range of 1–100 nanometers."**

**"It has been estimated that a gecko has a total of about one million setae on all its feet."**

*7) Ask the students:*

**"What is the significance that each seta contains between 100 and 1,000 spatulas?"**
*Students should conclude that with one million setae, each with 100–1000 spatula, there is a lot of potential for surface contact between the surface and the gecko.*

**"As the scale decreased, what did you find out about the structure of the gecko's toe?"**
*As the scale decreased, more and smaller structures became evident in the images.*

| | |
|---|---|
| Slide 7 | *8) As a culminating discussion, ask students to respond to the questions in "Making Connections."*<br>**"Let's review briefly your understanding."**<br>**1. "Describe one or two ideas that you learned during this lesson."**<br>**2. "Which range do gecko setae fit into?"**<br>*Micrometer scale*<br>**3. "Which force would make best use of these many points of contact?"**<br>*Adhesive force*<br>**4. "How might the gecko's foot structure help the gecko climb a wall or ceiling?"**<br>*Make sure to talk with the students about the structure of the gecko's foot being compliant with a surface.* |
| Slide 8 | *9) The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence. The following color code is used:*<br>*Yellow: Past Lessons*<br>*Blue: Current Lesson*<br>*Green: Next Lesson*<br>*White: Future Lessons* |

# Appendix: NanoLeap Physical Science Vocabulary for Lesson 4

**Adhesive**
Something that tends to remain in association or attachment

**Compliant**
1. Soft and able to conform to the surface of another object
2. Yielding to physical pressure

**Lamella (Lamellae plural)**
Each gecko toe pad is covered on its under surface by rows of wide scales

**Seta (Setae plural)**
Each gecko lamella is covered by fine projecting hairs or setae about 100 microns in length

**Spatula (Spatulas plural)**
The setae branch and sub-branch several times; the final twigs end in a pair of minute flattened tips called spatulas

**Surface terrain**
The physical features of a surface, usually referring to the topography

**Topography**
1. The physical or natural features of an object and their structural relationships
2. The depths and rises on a surface

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# MINI-ME

**Learning Objectives**

To understand the concept of scale
To relate to changes in scale
To learn how to accurately measure length and height

**Background:**

If the properties of matter are to be truly understood scientists need to be able to change their perspective to understand scale and size. How do we begin to understand a scale we cannot see, a scale that is characterized by less than one hundred millionth of a meter? First we must be able to see ourselves on a very small scale. We must be able to picture ourselves much smaller than what we are and sculpt an image that symbolizes our understanding of the invisible world. Imagine yourself 1/10 of your size, for example if your height is 5 feet your new size would be 6 inches. You will now sculpt a miniature of yourself from clay making sure to keep your height, and the length of your arms and lengths to 1/10 their normal size. You have moved from the meter scale to the centimeter scale. How much more would you need to shrink your sculpture to become the smallest size visible by your eye? ($10^{-4}$) You would need to shrink another 1000 times smaller than your sculpture. What if you were to shrink to nanosize? You would need to shrink the sculpture 10 million times? You would be the smallest size visible by a special microscope called an electron microscope. Think of the advantage you would have to understand how reactions occur if you could witness them. Now picture the sculpture of yourself as an atom, what would be the normal size of a person? A person would be as tall as the distance across the earth.

**Activity**

Construction of a Mini Me

**Materials:**

Pipe cleaners
Measuring Tapes
Crayola Modeling Clay

**Procedure:**

Each student is given pipe cleaners, a small lump of Crayola modeling clay and a measuring tape. The students should work in pairs and assist each other in measuring their height, and the length of their arm's span. Then each student should take two pipe cleaners and twist them to make the body and legs. Use one more pipe cleaner to make the arms. The length of the body should be 1/10 the student's height and the length of arms of the sculpture should be 1/10 that of the students arm's span. Then the crayola clay should be shaped around the pipe cleaner body and a head should also be fashioned from the clay and slid on the top of the body formed by the pipe cleaners. The sculpture should be allowed to dry and checked for accuracy.

After completing their mini-me have students repeat the process by making a $1/10^{th}$ scale model of their mini-me. This mini-mini-me will now be $1/100^{th}$ of their original size. Ask students how many more times they would need to do this process to make a nanome (7 more times).

This lesson is the product of the Institute for Chemical Education and the Nanoscale Science and Engineering Center at the University of Wisconsin-Madison. This Material is based upon work supported by the National Science Foundation under grant number DMR-0425880.

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# *Investigating Static Forces in Nature: The Mystery of the Gecko*
# Lesson 5: What Types of Forces Can Hold Objects Together?
# Activity: What Sticks?

**Student Learning Objectives:**

- Explain the properties of an adhesive
- Describe what happens when the surface of an object is brought into contact with the surface of another object
- Characterize different methods of adhesion
- Evaluate applicability of different methods to explain gecko adhesion

***Note: By the end of this lesson, students should have ruled out all mechanical methods of adhesion, leaving intermolecular forces to be explored in more detail in the subsequent lessons.***

**At a Glance for Teachers:**

- Exploration of different materials and their ability to adhere in stations
- Teacher demonstration with magnets
- Exploration of variables that affect adhesion
- Homework: Write a procedure to test the variables of two adhesives
- Read some research about different adhesion methods
- Complete an Adhesion Methods Debrief Chart *(Adhesion Methods Student Handout*)

Note: Some questions in the Student Journal are underlined as formative assessment checkpoints for you to check students' understanding of lesson objectives.

**Estimated Time:** 90–100 Minutes

**Vocabulary:** Adhesion, Adhesive
*Refer to the end of this Teacher Guide for definitions.*

**Materials:**

- PowerPoint for Lesson 5

- Student Journal for Lesson 5
- Copies of *Adhesion Methods Student Handout* (one complete packet per student group)
- Computer with LCD and overhead projector and magnets for teacher demonstration
- Set up materials in stations, as outlined in the table below, for the students to investigate:

| Station | Materials | Adhesion Methods Examples |
|---|---|---|
| 1 | Magnets, Paperclips, Plastic Transparency | Friction, Magnetic |
| 2 | Suction Cups, Plastic Transparency | Air Pressure (Suction) |
| 3 | Fur or Wool, Balloon, and/or Styrofoam™ Plate Paper Pieces and Plastic Transparency | Intermolecular Static Electricity |
| 4 | Beaker of Water, Paper Towel, Plastic Transparency | Capillary Wet Adhesion |
| 5 | Washers, Velcro®, Plastic Transparency | Micro-Interlocking: Velcro |
| 6 | Transparent Tape, Plastic Transparency | Intermolecular: Electrical |
| **Additional Stations** | | |
| 7 | Lego™, magnet | Mechanical Interlocking, Friction |
| 8 | water, hand, suction cups, table top | Capillary Wet Adhesion, Air Pressure |
| 9 | Play-doh™, clay, plastic lid (with raised surface-like lettering) | Capillary Wet Adhesion, Friction |

| **Slide #** **Student Journal Page #** | *Teacher Background Information and Pedagogy* **"Teacher Script"** |
|---|---|
| Slide 1<br>Title | 1) *This is a guided exploration activity. It is designed so that students will have an opportunity to determine many different ways for two objects to "stick" together. As you set up this activity, provide the materials in different stations and read the statement on Slide 2 out loud for students to begin their exploration.* |
| Slide 2 | 2) *Introduce the activity:*<br>**"You will be working at several stations using an assortment of materials to test and record some ways that objects adhere to the plastic transparency."**<br>*Explain to students that they will only be allowed 3–5 minutes per station to record their observations.* |
| Slide 3–4<br>Student Journal Page:<br>5–1<br>5–2<br>5–3<br>5–4 | 3) *Explain that for each station there is a recommended procedure, but they should also explore on their own. Instruct students to record their findings for each station in the table of their journal. Emphasize that during at least one station they should describe the factors or variables that affect how well the objects stick.* |
| Slide 3–4<br><br>Teacher Demonstration | 4) *Once students complete the "what sticks" activity, have them brainstorm other examples of objects that adhere together in similar ways as the materials in the activity. Record student responses on the board.*<br><br>**"What are some methods that caused the things to stick together?"**<br>*Students' answers from the pilot test included: suction, static electricity, magnetic force, interlocking, and water adhesion.*<br><br>*Dominant Forces:*<br>5) *Place two magnets on an overhead projector about 15 cm. apart. Ask students to describe the forces at work on each magnet and the resulting lack of motion. Slowly move one magnet closer to the second magnet. As the distance decreases, ask the students what force they were able to infer. (Magnetic force. Friction oppose the attractive magnetic force. As one magnet moves closer to the other, the magnetic force becomes dominant over friction.)* |

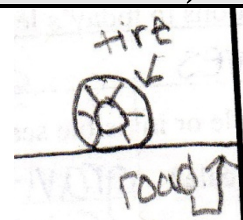
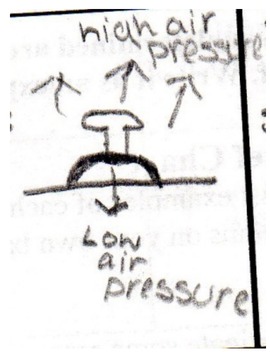
| | |
|---|---|
| Slide 5<br><br>Student Journal Pages: 5–4 | *6) This exercise helps students begin thinking about the many variables that affect adhesion. Once they have provided a list of variables, ask the students to indicate which are testable and which are not. Variables mentioned in the pilot test included the amount of wetness, temperature, mass of the objects, whether the objects were dirty or clean, and the amount of surface area or the amount of force applied.*<br>**1. "Choose one pair of objects that stuck together during your exploration. Then, in your journal, describe the factors or variables that affect how well those two objects stick together."**<br>**2. "Describe an adhesive in your own words. What are the properties that make them work?"**<br>**3. "Which factors or variables are testable and which are not?"** |
| Slide 6<br><br>Student Journal Page: 5–4 | *7)* Describe how you made observations in today's lesson.<br>a. What senses/tools did you use?<br>*seeing/feeling*<br>b. What observations were at the visible scale?<br>*answers will vary*<br>c. What dominant force did you observe?<br>*student answers may include: gravity, friction, magnetism etc.*<br>d. What are other forces that you observed that may be at the invisible scale?<br>*student answers may include: magnetism, static electricity, wet capillary adhesion, etc.* |
| Student Journal Page: 5–4 | **"Homework: Based on the factors that you determined are testable, write a plan to determine how a factor could be tested. Write it as an experimental procedure."**<br><br>*Explain to students that a good procedure clearly communicates a step-by-step process for completing the experiment. Included in the procedure are materials, how long you expect the experiment to take, and any other information that is important to completing the experiment. The plan should be detailed enough for another investigator to repeat the experiment just as you did originally[4]. Pilot teachers felt this was a good activity. It made students think for themselves and provided good practice in writing procedures.* |
| Slide 7<br><br>Student Journal Pages: 5–5 | *8) Referring to the Adhesion Methods Debrief Chart, prompt students by saying:*<br>**"From the information you gained in your experiment, complete columns two through four in the chart."**<br><br>*Once students have categorized the methods, have them write down what they know about each one. A key has been provided for the teacher at the end of this Teacher Guide. It is not intended to be shared with the students at this time.* |

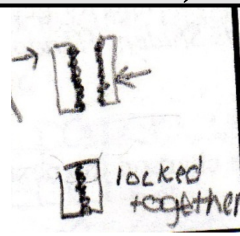
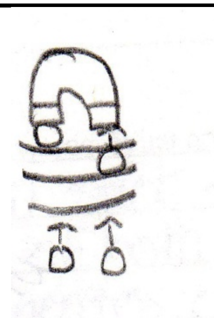
[4] Adapted from: Ramig, J.E., Bailer, J., & Ramsey, J. M. (1995). *Teaching science process skills*. Good Apple: Torrance, CA.

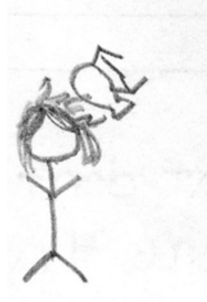
| Slide | Procedure |
| --- | --- |
| 5–6 | *Encourage students to write the definitions in their own words.* |
| 5–7 | 9) *Divide the class into seven groups (one for each method). After allowing time for students to complete columns 2-4 of the chart, resume the class discussion.*<br>**“Let’s return to the gecko problem. Do you think that any of the materials that you explored are similar to the gecko’s adhesion? Over the years, scientists have hypothesized many different possible methods for gecko adhesion.”**<br><br>**“Each of you will be assigned to one of seven teams for the purpose of reading some research findings from scientists who have studied different adhesion methods of geckos. You will learn from their research and determine the best hypothesis of what is happening with the gecko’s foot. Each team will receive a complete packet that contains the possible methods and some findings. Each person should take notes about what they read. Be prepared to report to the class what you have found. During each presentation, you will take notes while listening to the other groups’ presentations in your journal, the Adhesion Methods Debrief Chart for Slide 7.”** |
| | 10) *To complete the last two columns in the Adhesion Methods Debrief Chart**:*<br>• *Distribute the Adhesion Methods handout (one page/method per group).*<br>• *Give each group one method so that they can concentrate on that particular method.*<br>• *Prompt students to take notes in their journal on how the method works, how it might apply to the gecko, and any research that may have been done that might relate to the gecko.*<br>• *Debrief each of the methods as a whole class discussion.*<br>• *Debriefing should be completed by projecting each group’s handout onto a chalk board or white board and recording the students’ responses. Representatives from each method should present their work. The rest of the class should record these findings in their journal (pages 5-3 and 5-4) and discuss anything that is not clear in the presentation.* |
| | *Note to Teacher: There is no fundamental difference between capillary wet adhesion and the adhesion between tape and a surface. In both cases there are intermolecular forces between some substance and the surface. In one case it is water, in the other it is polymer applied to the tape. The distinction to be made here is that some remnants of water would be left behind after the two surfaces are detached for capillary wet adhesion. Tape may leave a residue whereas the gecko does not, but the example of tape should move students toward a better understanding of what is happening with the gecko.* |
| | 11) *Tell students to refer back to these notes in future lessons.* |

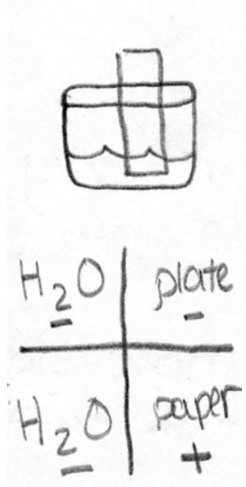
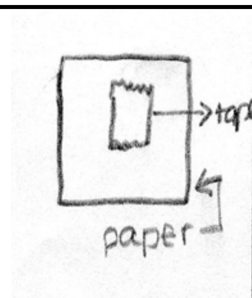
| | |
|---|---|
| | ** We recommend that this chart be developed on chart paper for each class so that it can be referred to in subsequent lessons.** |
| Slide 8 | *1) As a discussion, ask students to respond to the "Making Connections" questions on Slide 8.*<br>**"Let's recap what we learned in this lesson:**<br>**1. Describe one or two ideas that you learned during this lesson.**<br>**2. How do things stick together?**<br>**3. Which of these ways are likely to be used by the gecko to stick to a ceiling?**<br>**4. What should we explore next?"**<br><br>**"In the next lesson, we will explore how much force is needed to make an object stick to a ceiling as well as the amount of force that is acting between two objects."** |
| Slide 9 | *13) The pilot-test teachers highly recommend using this flow chart at the end and/or beginning of each lesson. The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence. The following color code is used:*<br>*Yellow: Past Lessons*<br>*Blue: Current Lesson*<br>*Green: Next Lesson*<br>*White: Future Lessons* |

# Appendix A: Answer Key for Adhesion Methods Debrief Chart

| Method | Definition | Drawing That Describes the Method (From Field Test Student) | Examples from Experiment (Slide 7) | Is this method a possible answer to the gecko mystery? (Yes or No) | Why or Why Not? |
|---|---|---|---|---|---|
| **Mechanical Force: Friction** | Friction is the force that opposes the lateral motion of two surfaces that are in contact. |   | paper clip and transparency<br><br>magnet on transparency | No | While there is friction between the gecko's foot and the surface, it only permits the gecko to move parallel to the surface. |
| **Mechanical Force: Suction** | Suction is the creation of a partial vacuum (region of low pressure). A suction cup is a device made of either plastic or rubber that sticks to smooth surfaces. |   | suction cup on transparency | No | Gecko force experiments indicate that the same force measurements have occurred when tested in a vacuum as in regular air.<br><br>During field tests students said that air is key for suction to work and geckos can climb in a "vacuum room." |

| Method | Definition | Drawing That Describes the Method (From Field Test Student) | Examples from Experiment (Slide 7) | Is this method a possible answer to the gecko mystery? (Yes or No) | Why or Why Not? |
|---|---|---|---|---|---|
| **Mechanical Force: Micro-interlocking** | Two materials may be mechanically interlocked. At the macroscopic scale, examples include: a zipper, sewing two pieces of cloth with a thread, and two pieces of Velcro® that are attached. |   | Velcro and transparency | No | No entanglement has been observed. In fact, force measurements have been the same amount per unit area for different opposing materials.<br><br>During field tests, students stated that there were no hooks on the geckos foot to attach itself to an object. |
| **Intermolecular Force: Magnetic** | A magnet is an object with a magnetic field. A “hard” magnet is one which stays magnetized for a long time. A “soft” magnet is one which loses its magnetic properties. Opposite poles of magnets attract. |  | magnet with paperclip | No | Gecko sticks on non-magnetic surfaces (e.g., glass, wood, concrete).<br><br>During field tests, students mentioned that geckos are not made of metal or cannot create a magnetic field. |

| Method | Definition | Drawing That Describes the Method (From Field Test Student) | Examples from Experiment (Slide 7) | Is this method a possible answer to the gecko mystery? (Yes or No) | Why or Why Not? |
|---|---|---|---|---|---|
| **Intermolecular Force: Static Electricity** | Static electricity involves the buildup of charge in objects due to contact between mostly nonconductive surfaces. These charges are generally built up through the flow of electrons from one object to another. These charges then remain in the object until a force is exerted that causes the charges to balance (e.g., the familiar phenomenon of a static "shock" is caused by the neutralization of charge built up in the body from contact with nonconductive surfaces.) |  | fur and balloon<br>fur and transparency | No | The adhesion force is independent of the types of opposing materials that the gecko is on. The gecko adheres equally while in clean air or heavily ionized air.<br><br>During the field test students noted that the gecko could stick to neutral surfaces. |

| Method | Definition | Drawing That Describes the Method (From Field Test Student) | Examples from Experiment (Slide 7) | Is this method a possible answer to the gecko mystery? (Yes or No) | Why or Why Not? |
|---|---|---|---|---|---|
| **Intermolecular Force: Electrical Capillary Wet Adhesion** | Water molecules are not only attracted to each other, but to any molecule with positive or negative charges. When you place paper from a straw partially into a glass of water, the water will “climb” up the fibers of the straw paper because the water molecules are attracted to the cellulose fibers in the straw paper. |  | beaker of water, paper towel, and transparency | No | Observations made with geckos indicate that there is no wet trail left behind when geckos walk on a surface. Skin glands are not present on gecko feet—the foot does not have a way to secrete any substance.<br><br>During the field test students noted that the gecko can stick to both wet and dry surfaces. |
| **Intermolecular Force: Electrical (Tape)** | Transparent tape has a rubbery composition that at the molecular level has properties similar to a liquid.<br><br>The tape makes intimate contact with |  | transparent tape and transparency | Possibly | For this method to be a possibility, each gecko seta must have a composition similar to the rubbery composition of the tape. This would then allow the seta to make |

| Method | Definition | Drawing That Describes the Method (From Field Test Student) | Examples from Experiment (Slide 7) | Is this method a possible answer to the gecko mystery? (Yes or No) | Why or Why Not? |
|---|---|---|---|---|---|
| | the surface so that more intermolecular electrical attractions occur to cause adhesion. | | | | intimate contact with the opposing surface.<br><br>Students should have observed in Lesson 4 that the spatulas do not have a liquid or sticky composition.<br><br>During field tests, students mention that “there is no adhesive stuff on a gecko’s foot.”<br><br>Explanation for teacher:<br><br>The forces, however, are different. The gecko is an induced-dipole (van der Waals, which are weak and temporary) interaction; whereas, the transparent tape is a dipole-dipole interaction. |

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**Note to Teacher:**

Intermolecular forces **are electromagnetic forces between molecules. These forces are much weaker than** intramolecular forces **(such as covalent bonds, ionic bonds, and metallic bonds). The following are examples of intermolecular forces from strongest to weakest: Hydrogen Bonds (Capillary Wet Adhesion), Dipole-Dipole Interactions (Hydrochloric acid), Momentary Dipole Interactions (van der Waals).**

# Appendix B: NanoLeap Physical Science Vocabulary for Lesson 5

**Adhesion**

1. The attraction exerted between the surfaces of objects. Can be either mechanical (e.g., suction, micro-interlocking, friction) or intermolecular (e.g., electrical and magnetic)
2. Objects in contact: steady or firm attachment of objects

**Adhesive**

A substance that helps objects stick together

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# *Investigating Static Forces in Nature: The Mystery of the Gecko*
# Lesson 6: How MUCH Force Is Needed to Make an Object Stick?
# What Factors Affect the STRENGTH of Force Acting on an Object?
# Explore

**Student Learning Objectives:**

- Explain that a net force of zero or greater is necessary for objects to adhere to a surface (wall or ceiling)
- Identify different variables and the constants that affect adhesive forces
- Explain how the amount of adhesion changes when the conditions of the surfaces change

<u>Note: Some questions in the Student Journal are underlined as formative assessment checkpoints for you to check students' understanding of lesson objectives.</u>

**At a Glance for Teachers:**

- Review what students know about forces
- Teacher demonstration on balanced forces
- Determine the amount of force needed for objects of varying masses to adhere to a ceiling and maintain a net force of zero
- Activity: Tape Pull—Measure the amount of force required to remove a piece of transparent tape with varying amounts of dirt

**Estimated Time:** 80 Minutes

Vocabulary: Adhere, Adhesive, Balanced Forces, Dependent Variable, Force, Independent Variable, Mass, Net Force, Newton, Unbalanced Force, Volume

*Refer to the end of this Teacher Guide for definitions.*

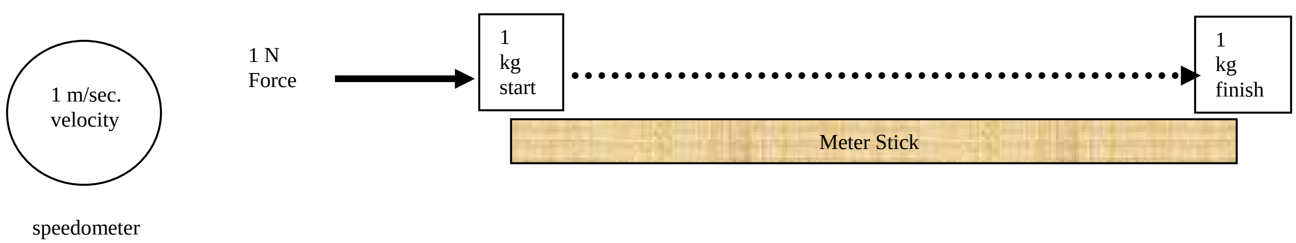
**Materials:**

- PowerPoint for Lesson 6
- Student Journals for Lesson 6
- Computer with LCD or overhead projector
- Duct tape
- 50 N spring scale
- Transparent tape
- Hole punch
- Ruler, protractor

**Safety Note**

Have students wear safety goggles in accordance with district safety policy.

| **<u>Slide #</u>**<br>**Student Journal Page #** | <u>*Teacher Background Information and Pedagogy*</u><br>**"Teacher Script"** |
|---|---|
| Slide 1<br>Title<br><br>Student<br>Journal<br>Page:<br>6–1 | 1) *Review with students that a* **force** *is a push or pull. See definitions in Appendix B.*<br>**"What is the meaning of the word force in science?"**<br><br>2) *Demonstrate balanced forces by partially filling a small jar with water. Place an index card underneath the rim of the jar and invert the jar while holding the index card. Next, release your hand from the card while carefully holding the jar. Students should note that the card remains in contact with the rim of the jar. Have students identify the balanced forces at work in this demonstration. Answer: air pressure is the dominate force, it is equal to the weight of the water plus the force of gravity. Other forces that are present but less dominate are gravity and capillary wet adhesion (if the card got wet when it came in contact with the rim of the glass).*<br>**"Is this demonstrating a balanced or unbalanced force? Why?"**<br><br>**"What would happen if this was an unbalanced force?"**<br><br>3) *Have students look around the room and identify pairs of objects that are at rest and represent balanced forces and record these in the box on the left side of the student journal. Students should identify the forces acting on each object and that the net force is zero. Have students draw one of the examples of balanced forces and indicate the amount of each force acting on the object using arrows in Student Journal page 6–1. Have students repeat this exercise for unbalanced forces in the box on the right side of the student journal. Note to teacher: if the object sits on a table, there is the upward normal force of the table on the object. Research has shown that students often don't recognize this as a force, they just indicate the table is in the way.]*<br><br>4) *Provide examples of objects in motion such as objects speeding up, slowing down, or at constant speed.*<br><br>*A field test teacher used a Frayer model for balanced and unbalanced forces for this lesson (refer to Lesson 1 for directions on the use of the Frayer model).* |
| Slide 2<br><br>Student<br>Journal | 5) *Display Slide 2*<br>**"In this image, there are two forces at work: one that is holding the shoe onto the ceiling and another that is pulling the shoe towards the floor. In order for the shoe to remain on the ceiling, what must be true about these two forces?"** |

| | |
|---|---|
| Page:<br>6–1 | *Students should state that these represent balanced forces (i.e., the net force is zero), or that the force holding a shoe is greater than the force of gravity. An example of the latter would be if the shoe contained a magnet that was attracted to a steel ceiling. This force could be greater than gravity, and then there would be an additional normal force acting in the direction of gravity to counteract the excess magnetic force.* |
| Slide 3<br><br>Student Journal Page:<br>6–2<br><br><br><br><br><br><br>Calculations In Appendix A | **"Imagine an ant, like the one on this slide, walking on the ceiling. Draw a picture representing the forces of the ant on the ceiling in your journal. Determine the force required for each ant foot (divide total force by six)."**<br><br>*Explain the following assumptions that are important for this problem:*<br>**"We are assuming in this problem that the total force required is equally divided among the six ant feet, and that ONLY the contact between feet and ceiling gives rise to the force."**<br><br>*The weight of the ant is provided in Newtons (N), a derived unit which is the force needed to increase the speed of (or accelerate) one kilogram of mass one meter per second every second.*<br><br>*A field test teacher passed around objects (e.g., a one Newton weight, an eight Newton cell phone) for students to be able to relate to this unit of measure.*<br><br>*For this module, there is no need to calculate force with Newton's Second Law of Motion. However, there may be a need to explain how an object's weight can be expressed in Newtons. Explain that in the metric system forces are measured in units of Newtons (using the symbol "N"). Provide students with the definition found in Appendix B along with the following illustration. Use these along with the direct vocabulary instruction strategy as described in the preface. Weight is action of the force of gravity on an object. A standard kilogram mass would therefore have a weight of 9.8 Newtons on Earth since the acceleration due to gravity is 9.8 m/s/s.*<br><br><br> |

| | |
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| | *6) Point out to students that the weight is the minimum amount of force that must be provided by the feet of the ant on the ceiling in order for there to be balanced forces and thus have the ant adhere to the ceiling. See Appendix A for the answers.*<br><br>***Note:*** *During the pilot test, students thought this activity was interesting. The calculations took a bit to understand, and it was valuable to review unit conversions. Use Appendix A to assist students in solving the first problem.* |
| Slide 4<br><br>Student Journal Page: 6–3 | *7) Display slide 4.*<br>**"Repeat the calculation—this time for an imaginary object that is larger in every dimension and whose mass and volume is ten times larger."**<br>*Determine how many "ant feet" it would take for this imaginary object to remain adhered to the ceiling. Compare and discuss the difference between the two calculations in class. See Appendix A for calculations.*<br><br><u>Teacher Demonstration:</u><br>*Optional: One pilot teacher added a calculation for a two-ton elephant as well. Actual weight for an African male elephant in Newtons is 122,580 Newtons. Refer to optional notes in Slide 5.* |
| Slide 5<br><br>Student Journal Pages: 6–3 6–4 | **"Let's return our attention to the gecko.**<br><br>**Repeat your calculations from the imaginary animal for the Tokay Gecko, which has an average weight of 2.2 Newtons."**<br><br>*8) Have students write a statement and/or draw pictures that describe the relationship between size (mass) and weight and, therefore, the adhesive forces required for an animal to remain on a ceiling.* |
| Slide 6 | *9) Explain to students that they will be using the following terms in this lesson.*<br>**"Adhere describes how something sticks to something else.**<br>**Separation force is the amount of pull that is required to detach two objects."** |
| Slide 7 | **"What are the tools that we can use in the laboratory to measure the amount of force that an object exerts? What are the units used when measuring with this tool?"**<br>*Forces can be measured with a spring scale that changes when a force is applied. Forces are measured in Newtons (N).* |
| Slide 8<br>Student Journal Page: | **"As you have observed a gecko adhering to a wall, you may have wondered about the types of surfaces that are required to accomplish this feat.**<br>**Can the gecko adhere to any surface?**<br>**Does the surface need to be clean or can the gecko adhere to dirty surfaces too?** |

| | |
|---|---|
| 6–4 | **What if the surface is wet? Will that affect how well the gecko can adhere?**<br>**To better understand how the gecko can adhere to different surfaces, we will be exploring the forces involved in the adhesion of transparent tape on a table top."**<br><br>10) *Tell students that over the next day or so, they will be able to refine this question based on how they set up their experiment.*<br>11) *Prior to showing slide 9 introduce the Tape Pull activity by having the students answer the question in their journal on page 6–4.* |
| Slide 9<br><br>Student Journal Pages:<br>6–5<br>6–6 | **"You will be working with transparent tape on the tabletop and measuring the force required to remove the tape with different amounts of dirt. This force, as stated previously, is actually GREATER THAN the adhesive force."**<br><br>12) *Before beginning the experiment have students work with the materials and practice the tape pull procedure as described on Student Journal page 6–5.*<br><br>**"Write down the independent variable (manipulated variable) and the dependent variable (responding variable)."** *Allow students to identify the amount of dirt as the independent variable and the force that it takes to remove or break the adhesion as the dependent variable.*<br><br>*Optional: Use the "sticky hands" toy (the one that initially sticks to glass then slowly falls/rolls down the glass) as a demonstration of dirt's effect. This toy's ability to stick decreases rapidly when it becomes dirty.*<br><br>13) *Hold a discussion about how to vary the "amount of dirt." For starters, students could test fresh (never before used) tape. Then, rather than adding dirt to the tape, students could make a finger print on the tape and test its adhesion. Other ideas: drop chalk dust onto tape and blow it off, touch the tape to the floor, etc. This then becomes the operational definition for the independent variable.*<br><br>14) *Hold a class discussion about how to keep certain variables constant, such as the amount of surface area in which there is contact between surfaces and the angle of pull. Based on this discussion, students should write a research question and a hypothesis before completing the activity. An example of a research question is given on this slide.* |
| Slide 10<br><br>Student Journal Pages:<br>6–6 | **"On this slide, you see how the materials are set up for the experiment. Image 6.8 shows a piece of tape on a table. The end of the tape that is pulled is reinforced with some electrical tape that has a hole punched through it. The hook end of the spring scale is then placed through the hole. Image 6.9 shows the spring scale being pulled at an angle (make sure this is the same each time). During the pull, a second student should carefully observe the force readings on the spring scale."** |

| | |
|---|---|
| 6–7<br>6–8<br>6–9 | *15) Allow students time to complete the activity as shown in the journal. As students are completing the procedure, make sure they refine their initial question and use their findings in order to provide explanations and further questions.*<br><br>*Student Journal pages 6–5 through 6–8 can be completed for homework and graded for use as a formative assessment.*<br><br>*Classroom Management Tip: One pilot teacher assigned jobs for the experiment:*<br>• *Tape handler and assembly*<br>• *Measurer*<br>• *Equipment Manager*<br><br>*16) After students are done with the experiment, have them answer the questions in their journal on page 6–9 and 6–10.*<br>Question 7:<br>Describe how you made your observations in today's lesson.<br>**a. "What tools did you use?"** (*spring scale)*<br>**b. "Were your observations at the visible or invisible scale?"** (*invisible)*<br>**c. "What is the dominant force at this scale?"** (*adhesive force/unknown)* |
| Slide 11 | **"What do you know about the effectiveness of transparent tape underwater, and how tape gets dirty over time? (***Display slide 11***) This is a quote from researcher Kellar Autumn, Assistant Professor of biology at Lewis & Clark College, about the self-cleaning ability of the gecko."**<br>*Students may state that when transparent tape is placed underwater, it will eventually lose its adhesiveness. Likewise, transparent tape does not work well on dirty surfaces.*<br><br>*17) It should be noted that ants leave a residue behind as they walk, whereas geckos do not.*<br><br>*18) Draw students' attention to the note on the slide about the gecko adhesion working underwater.*<br><br>*Optional: Students could test other variables: amount of tape contact area, cleanliness of the surface, etc.* |
| Slide 12 | *19) As a culminating class discussion, ask students to respond to the questions in "Making Connections."*<br>**"Let's review.**<br>**1. Describe one or two ideas that you learned during this lesson.**<br>**2. What factors contribute to the amount of force to remove a sticky substance?**<br>**3. How does dirt affect adhesion?**<br>**4. Do you think that a sticky substance is a possible method for the gecko adhesion?** |

| | |
|---|---|
| | **5. How do you think the gecko sticks to the ceiling?**<br>**6. What should we explore next?"** |
| Slide 13 | *20) The pilot-test teachers highly recommend using this flow chart at the end and/or beginning of each lesson. The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence. The following color code is used:*<br>*Yellow: Past Lessons*<br>*Blue: Current Lesson*<br>*Green: Next Lesson*<br>*White: Future Lesson* |

# Appendix A: Calculations and Possible Responses to Accompany PowerPoint Slides

**Slide 3 Calculations**
**Ant**
Weight of Ant = 0.00004 Newtons or $4 \times 10^{-5}$ Newtons
Weight of Ant/6 Ant Feet = Force for each foot = 0.0000067 Newtons per Ant Foot or $6.7\times 10^{-6}$ Newtons per Ant Foot

**Slide 4 Calculations**
**Ant Mass Times 10 times what it was before**
**Then IF the Ant Foot can ONLY support $6.7 \times 10^{-6}$ N, how many ant feet would be required?**
Weight of Imaginary object / Force for each Ant Foot
**$4 \times 10^{-4}$ Newtons/$6.7 \times 10^{-6}$ Newtons per Ant Foot**
**59.7 ant feet = 60 ant feet**

**Slide 5 Calculations**
**Gecko**
Weight of Gecko = 2.2 Newtons
**2.2 Newtons/$6.7 \times 10^{-6}$ Newtons per Ant Foot**
**328,358 ant feet**

From Liang, Autumn, Hsieh, Zesch, Chan, Fearing, Full, Kenny[5]:
43.4 N average sustained clinging force of gecko with 227.1 $mm^2$ pad area

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[5] Autumn, K., Liang, Y. A., Hsieh, S. T., Zesch, W., Chan, W. P., Kenny, T. W., Fearing, R., & Full, R. J. (2000). Adhesive force of a single gecko foot-hair. *Nature*, 405, 681-684.

**Slide 5 Calculations (Optional)**
**200 lb adult**
Weight of adult in Newtons = 888.9 Newtons
**888.9 Newtons/6.7 X $10^{-6}$ Newtons per Ant Foot**
**132,671,642 ant feet**

**27,000 lb African male elephant**
**Weight of elephant in Newtons = 122,580 Newtons**
**122,580 Newtons/6.7 x $10^{-6}$ Newtons per Ant Foot**
**18,295,522,390 ant feet**

# Appendix B: NanoLeap Physical Science Vocabulary for Lesson 6

**Adhere**
1. To hold fast or to stick
2. To bind to

**Adhesive**
A substance that helps objects stick together

**Balanced Forces**
For each force acting on a body, there is another force on the same body equal in magnitude and opposite in direction. A body is said to be at rest if it is being acted on by balanced forces.

**Dependent Variable**
A factor or condition that might be affected as a result of a change in the independent variable (also called a responding variable)

**Force**
1. Energy exerted
2. A push or a pull that acts on an object

**Independent Variable**
A factor or condition that is intentionally changed by an investigator or experiment to explore its effects on other factors (also called a manipulated variable)

**Mass**
1. A quantity of matter
2. A measurement of the quantity

**Net Force**
The resultant non-zero force due to an unbalanced force

**Newton**
A unit of force needed to change the speed of a kilogram of mass by one meter per second for every second that the force is acting on the mass

**Unbalanced Force**
When there is an individual force that is not being balanced by a force of equal magnitude and in the opposite direction. A body is said to be in motion if acted upon by unbalanced forces.

**Volume**
The amount of space occupied by a three-dimensional object (Length times Width times Height for a rectangular object)

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# *Investigating Static Forces in Nature: The Mystery of the Gecko*
# Lesson 7: How Do We Measure Forces at the Nanoscale Level?
# Elaborate

**Student Learning Objectives:**

- Compare and contrast model probe instruments with those that are used to make measurements of electric and magnetic forces at the nanoscale (AFM, MEMS)
- Model how instrument probes can be used to characterize surface interactions
- Describe how the topography of a surface relates to adhesion
- Interpret graphs of forces at the nanoscale level
- Consider the new evidence about surface topography and seta adhesive forces to evaluate remaining methods of gecko adhesion

**At a Glance for Teachers:**

- Activity: Topography of the Unknown—Simulate how a probe characterizes an object by converting numbers into an image
- Activity modeling an AFM with refrigerator magnet
- View a short video about the atomic force microscope
- Compare and contrast box probes with the atomic force microscope
- Teacher demonstration: how gecko setae tips fill in the spaces on a simulated smooth surface
- Interpret force graph of a single gecko seta as measured by a MEMS device

Note: Some questions in the Student Journal are underlined as formative assessment checkpoints for you to check students' understanding of lesson objectives.

**Estimated Time:** 90 Minutes

**Vocabulary:** Atomic Force Microscopy, Cantilever, Characterization, Integrated Circuit, Micro-Electro-Mechanical Systems (MEMS), Nanotechnology, Newton, Probe
*Refer to the end of this Teacher Guide for definitions.*

**Materials:**

- PowerPoint for Lesson 7
- Student Journals for Lesson 7
- VCR or computer with LCD or overhead projector
- Video "Atomic Force Microscope" http://www.mcrel.org/nanoleap/multimedia/index.asp

For Each Team:

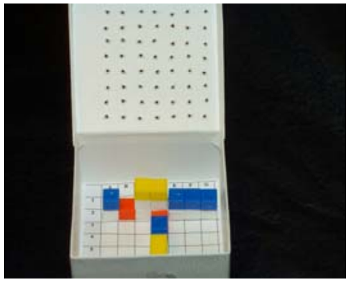
- 4x4x2 inch cardboard box with lid
- One white vinyl coated paperclip
- Fine tipped permanent markers (three colors)
- One centimeter plastic cubes
- Glue
- Scan paper (grid found in Student Journal page 7–2)
- Refrigerator magnet (and a magnetic strip to serve as a probe)
- Access to computers with Excel software

## Part 1: Advanced Preparations for Activity—Probing the Unknown: Topography of the Unknown

Note: It will save class time to have one box pre-made for each group of students.

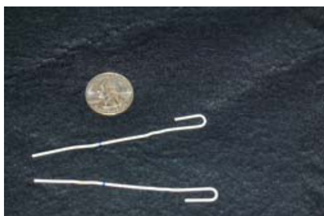
Image 7.1

1. Choose a side of the box lid and mark it with a "T." Choose a side of the box and mark it with a "T." Line up the two "T's," (lid and box) and this will be the top of your box when the lid is on the box.
2. Place one piece of scan paper on the lid of your box. Make sure the row of letters is at the top (along your "T"), and the column of numbers is along the left of the box. Tape it down.
3. Cut off the excess paper. Secure the paper with tape or glue.
4. On the box lid **only**, use a thumbtack to pierce a hole in the center of each square on the scan paper.



5. Open the box and place a new piece of scan paper at the bottom of the box. Make sure the row of letters is at the top (along the “T”), and the column of numbers is along the left side of the box. Tape it down.
6. Cut off the excess paper. Secure the paper with tape or glue.
7. Stack the cubes at three different heights and glue them down.
8. Place the box lid back on the box so that the “T’s” on the top of the lid and the top of the box are lined up.

Image 7.2



9. Straighten one end of the paperclip.
10. From this straightened end, measure and mark with permanent markers:
    - two centimeters from the tip, with one color marker
    - three centimeters from the tip, with a second color marker
    - four centimeters from the tip. with a third color marker
11. Make sure you encircle the entire circumference of the paperclip.

Image 7.3 (top)
Image 7.4 (bottom)

# Part 2: Demonstration—Modeling Setae Size and Filling in the Spaces

## Background:

**As students learned with the activity involving the shoes and charcoal dust, there is a significant difference between real and apparent contact between surfaces. Solid surfaces are rarely completely smooth (planar) and when observed up close, have a very definite topography. Therefore, real contact area only includes the places where surface of an object comes into actual contact with a surface terrain.**

**In this activity, students will have an opportunity to observe how a gecko seta's spatula-shaped tips, which in actuality are about 100-200 nanometers in width, allow them to adhere to apparently smooth surfaces. Students will view a demonstration of a model of a surface terrain and a model of the spatulas on a gecko seta in order to experience how size characteristics of the seta and their ability to comply allows for a large amount of real contact with a surface terrain.**

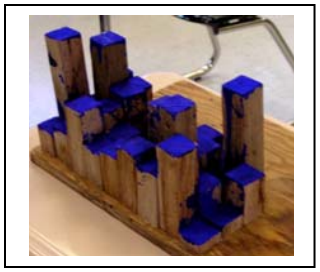
## Goal:

In this activity, students will view models of different configurations of gecko spatulas in order to model the effect of the number of spatulas on surface contact.

## Advanced Preparation for Part 2: Demonstration—Modeling Setae Size and Filling in the Spaces Activity

Create several models of the three-dimensional surface terrain**. Be sure to make the terrain varied**. Remember, few surfaces are really flat!

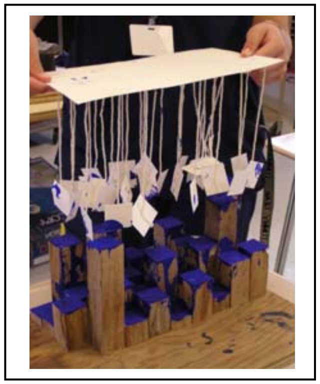
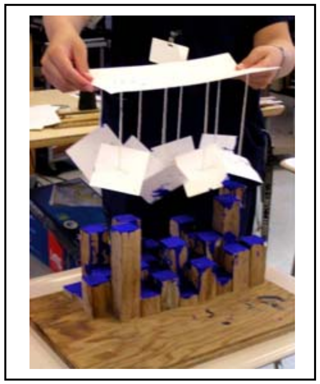
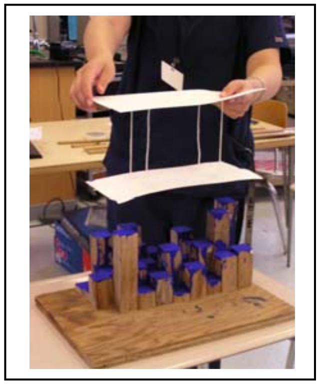
## Materials:



- Wooden blocks to make a three-dimensional terrain (like a relief map)
- Four 5x8 inch index cards (one to model the surface terrain, three to suspend the spatulas)
- One 5x8 inch index card to be used as a pattern for modeling spatulas
- Paper to model gecko spatulas
- Glue
- Scissors
- String
- Tape

Creating the Models of the Gecko Seta

1. The model will be made up of paper suspended by string on card stock.
2. Determine the number and size of the spatulas you will be creating (see PowerPoint slide 8).
3. Measure the length and width of the seta on paper and cut out the correct number for your model.
4. Attach the spatula tips to string using tape on the very middle of each seta.
5. Attach the string to the index card or card stock using tape.

| Slide # Student Journal Page # | *Teacher Background Information and Pedagogy* **"Teacher Script"** |
|---|---|
| Slide 1<br>Title | *1) In the activity "Probing the Unknown: Topography of the Unknown," students will characterize a surface up close. Advanced preparation includes assembling the observation boxes with a surface terrain made up of centimeter cubes. The students will use height probes to determine the surface height of the surface topography. After recording the height variations, students will create topographic maps of the surface using an Excel spreadsheet. Using these maps, students will analyze the data and the instrument used to collect the data.*<br><br>Part 1: Probing the Unknown<br>**"In this lesson, we will be investigating how nanotechnology instrumentation can be used to better understand the natural phenomenon of the gecko adhesion."** |
| Slide 2<br><br>Student Journal Page: 7–1 | *2) Discuss probes you have used in the physical science class. Include in the discussion how the probes have helped you identify properties of objects. In other words, these probes have helped you characterize objects.*<br>**"What are some instruments (probes) that you have you used in previous science classes?"**<br>*Students in the field test often included general materials such as glassware and Bunsen burners in their responses. Guide students to identify common probes such as a magnifying glass, a microscope, a telescope, a spring scale, litmus paper, a stethoscope, and computer probeware.*<br><br>*Introduce the pre-made boxes for the activity.*<br>**"We will begin by using a model to understand how surfaces can be characterized without being seen. Inside these boxes, I have a unique object. I can't see it. I can't feel it, yet I want to know something about it. Scientists use probes to characterize matter that we can and cannot see."** |
| Slide 3<br><br>Student Journal Pages: 7–1 7–2 | **"Today, we are going to use a straightened paper clip as a probe to determine the topography of a surface we cannot see."**<br>**"The image on this slide shows a top down view of a paperclip being inserted into a box to determine the shape inside the box. We are going to characterize the surface in each box. Then, you will make a scan of its appearance."**<br><br>*3) Have students write a procedure in their journals as you explain how to complete each step. For the first class using the boxes, demonstrate how to safely make the holes on the top lid using a thumbtack. Pierce the center of each square of the scan paper that is attached to the lid if it has not been previously done. Model how to insert the probe into the box.* |

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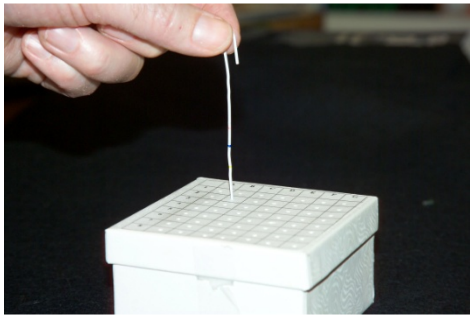
| | *Emphasize the importance of measuring straight down.*<br><br>*4) Once students can use the probe and understand how to measure the height of the object, proceed. Direct students to* ***systematically*** *measure and record the height of the surface at all probe holes.*<br><br>*5) Students can work in teams of between two and four students per group. Encourage each student to probe, measure, calculate, and record so that each student has the complete experience.*<br><br>*6) When recording the measurements, students should record on the scan area provided on page 7–2 of the journal or on an additional scan paper. If a student calculates 3 cm on the lid, grid A5, they should find A5 on the scan paper, and write 3 cm.* |
| Slide 4<br><br>Student Journal Page: 7–3 | **"You will be following the directions in the Student Journal and using an Excel spreadsheet to create a three-dimensional representation of the objects in your box."**<br><br>*7) Optional: Once students are done, have them complete the analysis question in their journal. Then allow them to view what's inside of the box. Comparison with the actual arrangement in the box is very important as well. It provides a visual reminder of the uncertainty inherent in any such indirect process. The instrument can be counted on to reveal some information about the surface topography, but there is always uncertainty; it is never an exact replica. If you allow students to look at what is in the box, remind them that in a real situation, they can never "actually open the box and see what's really inside." In this case the students are constructing a model of the surface topography; models are never exact replicas.*<br><br>*To save time, a field test teacher entered one student's data into the Excel spreadsheet to demonstrate how the numbers* |

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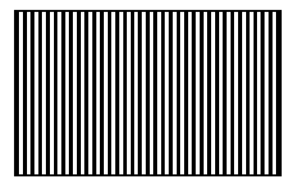
| | *translate into an image and displayed it via Smartboard™.*<br>*Atomic Force Microscopy is often used to map out the topography of surfaces at the nano level. The probe can be small enough so that the end of the tip is a single atom. The distance between the tip and the surface is the thickness of a couple of atoms.*<br><br>*Optional: Have students print and staple their graphs to their journal.* |
| Slide 5<br><br>Student Journal Pages:<br>7–3<br>7–4 | **"Atomic Force Microscopy is an example of a scanning probe microscope. In scanning probe microscopes, a tiny probe moves across the surface of the test materials. In Atomic Force Microscopes (AFM), cantilevers are used to detect surface <u>topography</u> by measuring attractive or repulsive forces between the tip and the surface to reveal the surface roughness of seemingly smooth surfaces. This model helps demonstrate the nature of the surface to which the gecko is adhering."**<br><br>*8) Show a short video "Atomic Force Microscope," available at: http://www.mcrel.org/nanoleap/multimedia/index.asp or on the CD. The video demonstrates how an Atomic Force Microscope or AFM is used to image the surface of a DVD.*<br><br>*9) As students watch the video, have them answer the following questions:*<br>*1. What does AFM stand for?*<br>*2. What does the AFM do?*<br>*3. How does the AFM do it?*<br><br>*10) Distribute refrigerator magnets and magnetic probe strips to each group of students for the AFM modeling activity. For their drawings, ask them to draw the forces as looking from the top down. As a follow-up discussion, ask students to consider:*<br>**"How does the distance from the probe to the surface affect the force that is measured?"**<br>*Using the magnetic probe, the students should explicitly note that the closer the probe is to the surface, the greater the force that is measured.*<br><br>*Student drawings may include alternating bumps on a surface. See example at right:*<br> |
| Slide 6<br>Student Journal Page:<br>7–4 | *11) Have students use the comparison matrix on page 7–4 of the Student Journal to compare and contrast two or three characteristics of the AFM as described in the video and the model height probes used in class. (See Appendix A for possible answers.)* |

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| Slide 7 | **Part 2: Demonstration: Modeling Setae Size and Filling in the Spaces**<br>*12) Explain to students that in this demonstration, you will be modeling how the spatulas on a gecko's seta come into contact with a surface. Emphasize that the surface topography being portrayed in this model is exaggerated in order to view how the spatulas interact with the surface.*<br><br>*A field test teacher asked students to build their own models.*<br><br>**"Question: How do gecko spatulas of a seta affect the amount of surface contact?**<br>**Prediction: How do you think the number of spatulas will affect the amount of contact between the gecko and the terrain?"** |
| Slide 8<br><br>Student Journal Page: 7–5 | **"Each seta model can be lowered onto the terrain. Make observations about the amount of opportunity for contact that occurs for each test."**<br><br>*The first image shows an example of how a surface might be constructed. The second image shows a model seta with one large spatula. The third image shows a model seta with four spatula-shaped tips. The last image at right shows a model seta with twelve smaller spatula-shaped tips.* |
| Slide 9<br><br>Student Journal Page: 7–5 | **"This image shows a compliant surface on a hard surface. How is this image similar to what was modeled in the teacher demonstration? How is it similar to the transparent tape on table activity?"**<br><br>*13) This model demonstrated how surfaces can come into very close contact. The transparent tape must have the characteristics of a liquid. Without having liquid properties, the gecko seta has many spatula-shaped tips that can get into the nooks and crannies of a surface.*<br>**"Remember from the AFM (magnetic probe, slide 5 and video), the closer the probe is to the surface, the greater the force that is measured."** |
| Slide 10<br><br>Student Journal Page: 7–5 | **"These artist's sketches illustrate two views of the spatula-shaped tips on a seta in contact with a rough surface like a wall. How are these drawings similar to the demonstration? How are they different?"**<br><br>*The sketches are similar to the demonstration in that the spatulas in both come into contact with the nooks and crannies of the seemingly smooth surface. However, the model with the cubes showed a much rougher surface than what is shown in the sketches.* |
| Slide 11<br>Student | **"How does the number of model spatulas on a gecko seta affect the opportunity for surface contact?**<br>**Based on what you observed about the gecko seta at the nanoscale level on slide 8, how does this model** |

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| Journal Page: 7–5 | **demonstrate the amount of opportunity for contact that the spatulas have with a surface?"**<br><br>*14) Refer students to slide 7 for the chart including adhesion methods from Lesson 5.* |
| Slide 12 | *Teacher Background:*<br>*MEMS stands for Micro-Electro-Mechanical Systems. These mechanical structures are made using the same type of equipment (mechanical elements, sensors, actuators, and electronics on a common silicon substrate) that is used for Integrated Circuits. Many MEMS sensors detect signals by detecting a physical force. The device measures force two ways. One is the vertical force down onto the sensor. The second is the lateral force.*<br><br>*15) Display slide 12*<br>**"Researchers at Stanford Nanofabrication Facility used a special technology called MEMS (a horizontal force probe) to measure the adhesive force of a single gecko seta. MEMS stands for Micro-Electro-Mechanical Systems. In this image, one gecko seta is seen on a MEMS device prior to it being pulled to the side in order to measure the adhesive force.**<br><br>**What force units do you think a single gecko seta would have? microNewtons? nanoNewtons?"**<br><br>*Accept all student responses before proceeding to Slide 13.* |
| Slide 13<br><br>Student Journal Pages: 7–6 7–7 | *16) Display slide 13.*<br>**"The following graph represents the adhesive force measurement of a single gecko seta. The seta was placed on the tip of a triangular cantilever and dragged across the probe laterally in order to measure the force between the seta and the probe as the seta slides across the probe and is removed from the cantilever."**<br><br>**"What is being shown on the X-axis and Y-axis?"**<br>**"What units are being used?"**<br>*Y-axis shows the sensor output force measured in microNewtons. X-axis shows the time measured in seconds.*<br><br>**"Based on the graph, describe what is happening to the force between the seta and the cantilever as time goes by."**<br><br>*17) For the last question, you may need to use the following prompts:*<br><br>**"What is happening between points A and B?"**<br>*This is where the sliding begins. Students might say that the force stays the same for two seconds, then increases at a high rate for two seconds.* |

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| | **"What is happening between points B and C?"**<br>*Students should note that the adhesion has reached a maximum force and stays constant.*<br>*Students may note that the seta appear to be coming off the probe surface as the seta approaches point C.*<br>**"Describe what is happening between points C and D."**<br>*Students should note that the seta slides off the probe surface by point D. They should observe that the force decreases at a high rate and drops down to zero.*<br><br>*18) To help students interpret the graph, you may want to ask questions like:*<br>• **"What is the maximum force that is measured for adhesion?"**<br>*(About 180 microNewtons)*<br>• **"Knowing that there are 1 million setae on all four feet, is this enough force to hold up a 2.2 Newton gecko?"**<br>*(Yes! 180 μN * 10^6 =180 N)*<br>• **"What questions do you have about this lateral force curve?"**<br>*(Student answers will vary.)*<br><br>*Optional:*<br>*Some students will notice that the initial force measurement is less than zero. Ask them to consider why the force measurement begins at less than zero microNewtons? (Perhaps due to pressing the seta onto the sensor)*<br><br>*Note: From Liang, Autumn, Hsieh, Zesch, Chan, Fearing, Full, Kenny[6]:*<br>*43.4 N average sustained clinging force of gecko with 227.1 $mm^2$ pad area* |
| Slide 14 | **"The maximum force presumably is reached when nearly all of the spatulas are in contact with the sensor surface. Initially unattached spatulas can be pulled into contact with the surface by their neighbors through sliding. Most importantly, adhesion increases significantly if the seta is dragged a short distance across the surface. All these can be attributed to the increase in number of spatulas that come in contact with the surface..."[7]**<br><br>*19) You might want to model this again using the seta demonstration from earlier in this lesson. You can use the analogy of a string mop across the surface model (from slide 8) to illustrate this phenomenon. When the strings on a mop are* |

[6] Autumn, K., Liang, Y. A., Hsieh, S. T., Zesch, W., Chan, W. P., Kenny, T. W., Fearing, R., & Full, R. J. (2000). Adhesive force of a single gecko foot-hair. *Nature*, 405, 681-684.

[7] Autumn, K., Liang, Y. A., Hsieh, S. T., Zesch, W., Chan, W. P., Kenny, T. W., Fearing, R., & Full, R. J. (2000). Adhesive force of a single gecko foot-hair. *Nature*, 405, 681-684.

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| | *unorganized, they would have less force when pressed to a surface than if the mop strings were all lined up and in the nooks and crannies. Remind students of the experiment they did using the spring scale to pull a piece of tape off the surface on which it was stuck? Although the students didn't quite pull the scale horizontally, they could imagine having done that.* |
| Slide 15 | *20) As a discussion, ask students to respond to the questions in "Making Connections."*<br>**"How are AFM and the MEMS devices used to help understand gecko adhesion?"**<br>*Students should understand the difference between AFM, which is used to image the surface of an object, and the MEMS, which are used to make force measurements.*<br><br>**"What do we now know about the amount of force between a single seta and a surface?"**<br>*Based on information from this graph, the seta provides 180 μN of force; the one million setae on all four feet provide 180 N. This is more than enough to hold up a 2.2 N. gecko.*<br><br>**"How does this new information help us understand the adhesion method for the gecko?"**<br>*Evidence from the graph indicates that there was smooth sliding with the removal of the gecko seta, which is similar to removal of tape from a surface. Capillary wet adhesion has been ruled out because geckos do not leave a wet trail. Electrical forces similar to tape require a liquid property not found on the gecko setae.*<br><br>**"What should we explore next?"**<br>*An intermolecular electric force that does not involve a liquid adhesive (Capillary Wet Adhesion) is needed.*<br><br>**"We will investigate the nature of the forces involved in gecko adhesion and 'solve' the mystery in the next lesson."** |
| Slide 16 | *21) The pilot-test teachers highly recommend using this flow chart at the end and/or beginning of each lesson. The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence. The following color code is used:*<br>*Yellow: Past Lessons*<br>*Blue: Current Lesson*<br>*Green: Next Lesson*<br>*White: Future Lesson* |

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| Before Lesson 8 ★ | *During pilot tests, teachers said that students benefited from a review of atomic structure prior to Lesson 8. Those physical science teachers that taught chemistry before physics concepts in their course sequence found that the concepts for Lesson 8 were much easier than those that taught the physics concepts first.*<br><br>*For a review of basic atomic structure, you may use your normal curricular resources. A brief PowerPoint included on the CD based on a module found at the following Web site can also be used to review these concepts:*<br>http://genesismission.jpl.nasa.gov/educate/kitchen/techappl/index.html<br>http://genesismission.jpl.nasa.gov/educate/scimodule/UnderElem/index.html |

# Appendix A: Answer Key for Comparison of AFM and Box Model (Slide 6)

| | AFM | Box Model |
|---|---|---|
| What characteristic is measured by the probe? | *Surface topography* | *Height of object in box* |
| How is this measured by the probe? | *By measuring the forces that change with distance between probe and surface* | *By direct contact of probe to surface* |

# Appendix B: NanoLeap Physical Science Vocabulary for Lesson 7

**Atomic Force Microscope (AFM)**
A type of scanning probe microscope in which a probe (usually a small cantilever with pointed top at the end) moves across the surface of a nanoscale object in order to measure surface properties, especially interactive and repulsive forces and the topography

**Cantilever**
A device used to detect and measure the amount of attraction or repulsion of the surface of an object

**Characterization**
The act of distinguishing or describing traits, qualities, or properties

**Integrated Circuit**
A tiny fabricated complex of electronic components, such as transistors, and their electrical connections, that is produced in the surface region of a small slice of material such as silicon (also called a silicon chip or computer chip)

**Micro-Electro-Mechanical System (MEMS)**
A small micro-machined device that combines electrical and mechanical elements at the micro or nanoscale to either sense or measure something (such as forces), to actuate something (cause motion, for example) or both

**Nanotechnology**
1. Manipulating materials on the atomic or molecular scale
2. The science of manufacturing materials and machines at the nanometer scale

**Newton**
A unit of force needed to change the speed of a kilogram of mass by one meter per second for every second that the force is acting on the mass

**Probe**
1. An object that is inserted into something so as to test conditions at a given point
2. A device used to penetrate or send back information

# *Investigating Static Forces in Nature: The Mystery of the Gecko*
# Lesson 8: How Can a Gecko Walk on a Ceiling?
# Evaluate

**Student Learning Objectives:**

- Describe the attractive forces between and within molecules that cause the gecko to adhere to a vertical surface
- Describe how a large number of small forces (van der Waals interactions) at the nanoscale level can add up to macroscopic forces
- Describe how a gecko can adhere to a ceiling by drawing on learning experiences throughout module

**At a Glance for Teachers:**

- Compare transparent tape and gecko adhesion
- Explore positive and negative charges with a computer interactive simulation
    - Positive and negative charges (charge simulator and hot spots)
    - Investigate weak forces
- Interpret diagrams showing atoms and their charges
- View *Sticky Subjects* and *Nano in Nature* video and summarize research findings
- Complete final essay assessment using the Peer Review Scoring Guide

Note: Some questions in the Student Journal are underlined as formative assessment checkpoints for you to check students' understanding of lesson objectives.

**Estimated Time:** 90 Minutes for Lesson 8; 75 Minutes for full Essay Assessment, 45 minutes without peer review

**Vocabulary:** Atom, Electron, Electron Cloud, Nanotube, Negatively Charged, Nucleus, Positively Charged, Proton
*Refer to the end of this Teacher Guide for definitions.*

**Materials:**

- PowerPoint for Lesson 8
- Student Journals for Lesson 8
- Computers with Internet access for student groups
- Computer with LCD or overhead projector

**Multimedia Resources:**

- *Nano in Nature* video located at: http://www7.nationalgeographic.com/ngm/0606/feature4/multimedia.html
- *Sticky Subject:* ScienCentral “Animal Oddities” at: http://www.youtube.com/watch?v=gB68Eb1KLa8

**For Essay Assessment: Demonstrate Your Understanding**

- Completed Student Journal sheets from the entire module
- Explanation of Essay Assessment: Demonstrate Your Understanding (Note: These are the last two pages of the Student Journal from Lesson 8)
- Copies of Peer Review Scoring Guide (2 per student); Handouts to be made for students located in the Teacher Guide
- For the instructor: Anchor Papers for Essay Assessment (See Appendix A of this Teacher Guide)

**Advanced Preparation: Load and test the Web sites at least one day in advance of the lesson**

- *Ion Engine Hotspots Game:* http://dawn.jpl.nasa.gov/mission/ion_engine_interactive/lev2/index.html
- *Charge Simulator:* http://dawn.jpl.nasa.gov/mission/ion_engine_interactive/lev1/index.html
- *Balloons and Static Electricity:* http://phet.colorado.edu/simulations/index.php?cat=Electricity_Magnets_and_Circuits

| **<u>Slide #</u>**<br>**Student Journal Page #** | <u>*Teacher Background Information and Pedagogy*</u><br>**"Teacher Script"** |
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| Slide 1<br>Title | 1) *Remind students about the concept of static electricity by recalling what happens when a Styrofoam® plate or balloon is rubbed with fur and can stick to a surface.*<br>*Optional: Demonstrate this for the class. Then, hit the charged object (balloon or plate) on a desk to return it to neutral.*<br><br>*Optional Computer Simulation available at:*<br>*[http://phet.colorado.edu/simulations/index.php?cat=Electricity_Magnets_and_Circuits](http://phet.colorado.edu/simulations/index.php?cat=Electricity_Magnets_and_Circuits)*<br>*Click on "Balloons and Static Electricity"* |
| Slide 2<br><br>Student Journal Page:<br>8–1<br><br>☆ | **"Let's take a look at what is happening at the end of the gecko seta. Recall the activities that you have done within this module. How do the spatula shaped tips of the setae come into close contact with the surface?"**<br>*The image on the slide shows the spatula-shaped tips at the end of a single gecko seta. Each spatula is about 100 nanometers thick.*<br><br>2) *Show the model from Lesson 7. Students should recall that the spatula-shaped tips come into very close contact with the surface to which it is adhering by fitting into the nooks and crannies of the seemingly smooth surface. This allows for a large amount of surface contact to be made per total surface area.*<br><br>*Note: You may want to review the progression of slides that depict the gecko foot structure close up from Lesson 4 (slide 6).* |
| Slide 3<br><br>Student Journal Page:<br>8–1 | **"How is the gecko seta similar to the transparent tape example? How is the gecko seta different than transparent tape?"** *Gecko adhesion is similar to transparent tape in that both comply to their respective surfaces. Some students in the field test stated that both are "squishy" or like an "adhesive liquid." It is different in that tape will lose its stickiness and leaves a residue, seta do not. In fact, setae are self cleaning.*<br><br>**"The image on the top of this slide is an artist's sketch of the spatula-shaped tips in contact with the surface (like a smooth piece of glass). How does this relate to the model that we developed with the spatulas and blocks in lesson seven?"** *It shows how the spatula shaped tips fit in nooks and crannies.*<br><br>**"Let's take a closer look at the molecular level to examine what is happening between the gecko seta and the surface."** |

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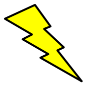
| | 3) *Explain that the image at the bottom of this slide shows transparent tape on a black lab table highlighted with white out similar to what they did in a previous lesson.*<br><br>***Teacher Information****: Both transparent tape and gecko adhesion make use of intermolecular forces. The transparent tape must have the characteristics of a liquid. The gecko seta has many spatula-shaped tips that can get into the nooks and crannies of a surface. Both are compliant with the opposing surface as shown in the diagram at right.* |
| Slide 4<br> | **"How does the kind of charge on a particle affect the deflection of a positively charged particle?"**<br><br>4) *Have students play the "Charge Simulator" or "Hot Spots Game" (about 15 minutes) at:*<br>*http://dawn.jpl.nasa.gov/mission/ion_engine_interactive/lev2/index.html*<br>*http://dawn.jpl.nasa.gov/mission/ion_engine_interactive/lev1/index.html* |
| Slide 5<br><br>Student Journal Page: 8–1 | 5) *Once students have played for several minutes, give them a chance to play the games and answer the questions for slide 5 in their journals. "Players and soccer balls" are used in the Hot Spots game, "dots" are used for Charge Simulator. The questions below can be used for either.*<br>**1. "What is the effect of placing a <u>negatively</u> charged player (red dot) close to the path of the positively charged soccer ball? (blue dot)"**<br>*Students should indicate that the positive soccer ball (blue dot) is attracted to the negatively charged player (red dot).*<br><br>**2. "What is the effect of placing a <u>positively</u> charged player (blue dot) close to the path of the positively charged soccer ball? (blue dot)"**<br>*Students should indicate that the positive soccer ball (blue dot) is repelled by the positively charged player (blue dot).*<br><br>**3. "What are your thoughts about the gecko seta surface and the ceiling surface as they relate to charges?"**<br>*Students might indicate that there are charged particles on the surfaces. Students might think that one surface is positive and the other is negative causing an attraction.* |
| Slide 6-7<br>Student Journal Page: 8–2 | 6) *Allow the students to observe and record their descriptions in their journals. Lead them to an understanding that the spheres represent atoms and the different groupings of spheres represent molecules. Explain that atoms and molecules are attracted to each other (positives attract to negatives and neutral particles) and that this attraction is an* ***electrical force,*** *which sometimes causes them to stick together. Explain that this animation represents the weakest interaction, which is temporary between atoms or molecules.* |

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| | **"In your journal are illustrations of weak attractions between molecules as shown in the animation. Identify the illustration that shows:"**<br><br>1. The attraction between two polar molecules. (A)<br>2. The attraction between two non-polar molecules. (C)<br>3. The attraction between a polar and non-polar molecule. (B)<br><br>*7) Show the animation on slide 6 "Weak Attractions."*<br>**"View the animation. The dashed lines represent an attraction."**<br><br>**4. "What makes you think that these are weak?"**<br>*Most students will indicate that these are weak forces because they are easily broken.*<br><br>**5. "Are these permanent or temporary attractions? How long do they last?"**<br>*Temporary* **because** *the molecules are in constant motion, and they tend to move away from each other fairly quickly.* |
| Slide 8<br>Student Journal Page:<br>8–3 | **"What is the overall charge of each atom in this diagram?"**<br>*Neutral*<br><br>**"In the diagram, what side of the atom is more negative?"**<br>*Left*<br><br>**"Not including the nucleus, what side of the atom is less negative?"**<br>*Right*<br><br>**"Would the two atoms attract or repel? Explain your answer"**<br>*Guide students to realize that the left side of image 8.9 is more negative than the right side of 8.8. This results in an attraction.*<br><br>**"Would the two atoms attract or repel?"**<br>*Students might suggest that they will have an attraction.* |
| Slide 9 | **"What is the overall charge of each atom in this diagram?"**<br>*Neutral*<br><br>**"What happens when you put two atoms like this side by side?"** |

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| | *Allow students to speculate.*<br><br>**"Would the two atoms attract or repel?"**<br>*Ask them to justify their answer.* |
| Slide 10<br><br>Student Journal Page: 8–3 | **"In this slide, we will show what is happening between the surface and a single seta. Image 8.12 shows the seta on a probe surface. The red lines show a magnified view of each surface. Image 8.13 shows the surface of a seta with spatula-shaped tips, and image 8.14 shows a drawing of the probe surface. Image 8.15 shows what might be happening between one atom on the probe surface and one atom on the spatula."**<br><br>*8) Draw student's attention to image 8.15. Note that the distribution of the electrons there are more on the left of each atom, causing an attractive force. Explain to students that these forces are very weak and temporary.*<br><br>**"We found in lesson six that on average a gecko would need to have an adhesive force of about 2.2 Newtons in order to adhere to a surface. Based on an average single seta force of 180 microNewtons (or 0.00018 Newtons) and if a gecko has approximately one million setae, how much potential force is available to the gecko?"**<br>*0.00018 Newtons times 1 million setae = 180 potential Newtons for the gecko to adhere to a ceiling if all setae were used equally.*<br><br>*Note: The researchers found that geckos sustain an average of 43.4 N of clinging force with 227.1 mm$^2$ pad area. (see reference in footnote below)*<br><br>**"What we have found is that gravity plays an insignificant role at the nanoscale level. Instead the gecko has these small intermolecular forces between each seta and the surface it is adhering to, resulting in a billion points of contact, which, when added up, is enough force to hold an entire gecko onto a vertical surface."**<br><br>***Teacher Background:***<br>*A dipole is a pair of electric charges or magnetic poles of equal magnitude but opposite polarity (opposite electronic charges), separated by some, usually small, distance.*<br><br>*The following is a quote about the type of force that scientists think is at work between the gecko setae and a surface:*<br>*Van der Waals attractions occur when objects are close together. There is a fluctuation in the electron distribution (electrons are slightly correlated) resulting in a very weak attractive force. Van der Waals may be significant when there is a large area of contact between objects that are close together...calculations of the complete van der Waals force between two complex macro-scale objects are simply too complicated to perform, and therefore adhesion force measurements* |

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| | *on...individual setae are necessary for verifying the van der Waals mechanism.*[8]<br><br>*Electrons are always moving around in an electron cloud. In general, the more room that electrons have, the more they can move. Image 8.15 depicts a momentary fluctuation creating a temporary dipole in a molecule that is usually non-polar. As this happens, electrons are pushed away in some places and toward other places. This momentary dipole induces another dipole to be created in a nearby molecule resulting in an attractive interaction. These weak interactions, known as induced-dipole/induced-dipole interactions, are always attractive and can occur between two particles in order to lower the total energy in a system. However, the interactions add up when large areas are involved. The PhET balloon and static electricity simulation shows momentary polarization of the charges on the wall when the charged balloon is brought near; although not a neutral-neutral interaction, it does show induced polarization.* |
| Slides 11–13<br><br>Student Journal Page: 8–4 | *9) Direct students to view the animations on slides 11 and 12.*<br><br>*For slide 12, prompt students to consider the following:*<br>**“Which molecule has the most contact with the green molecule? Explain your answer.”**<br>*Molecule one has many more surface contact than molecule two because of its shape.*<br><br>**“Explain how shape affects the number of attractions between the object and the surface.”**<br>*If the shape is more compliant (can fit into nooks and crannies) with the surface, then more attractions are possible.*<br><br>**“Which molecule acts most like the gecko seta? Explain your answer”**<br>*Molecule one fits into the nooks and crannies of the green (surface) molecule. The gecko setae can form intimate contact with most any surface resulting in the many intermolecular electric attractions required to adhere to a surface.* |
| Slide 14 | *10) Students should work in small groups to answer these questions. Note there is an additional question in the Student Journal that is not included here.*<br>**“Use the questions on this slide to develop your answer for the gecko adhesion problem. In the essay assessment, you will be asked to describe these forces in detail.”**<br><br>**“Describe the number and strength of forces involved in gecko adhesion.”**<br>*There are a large number of very small forces at work in gecko adhesion.*<br><br>**“What part of the atom moves in response to momentary charge rearrangements?”** |

[8] Autumn, K., Liang, Y. A., Hsieh, S. T., Zesch, W., Chan, W. P., Kenny, T. W., Fearing, R., & Full, R. J. (2000). Adhesive force of a single gecko foot-hair. *Nature*, 405, 681-684.

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| | *The electrons*<br><br>**"Describe this interaction between the electrons of each atom. Describe the overall charge and how long the attraction lasts."**<br>*While the atoms may be neutral, the electrons in their orbits were temporarily attracted or repelled.* |
| Slide 15 | **"So what? How does this help us in our everyday world? If scientists know more about this natural adhesive, they can potentially develop an artificial adhesive. What could an artificial adhesive be used for that has the following characteristics?"**<br><br>**An artificial adhesive that:**<br>• **Has all of the adhesive ability of a gecko**<br>• **Lasts forever**<br>• **Leaves no residue behind on the surface**<br><br>*11) Play the Sticky Subject: Sciencentral "animal oddities" a 42 second video found at: http://www.youtube.com/watch?v=gB68Eb1KLa8*<br><br>*12) Play the "Nano in Nature" video clip found at: http://www7.nationalgeographic.com/ngm/0606/feature4/multimedia.html*<br><br>*13) Review the bulleted list of research findings on the slide. Note that it is still not clear how the gecko can walk through dirt, and then self-clean so quickly. Explain that this represents another question that can be explored by students in the future.*<br><br>"**Brainstorm a list of potential applications for an artificial adhesive.**"<br><br>*14) Encourage students to be creative in their thinking. Students may want to think about all the ways duct tape is used. Some students have really used duct tape in really useful ways in art and technical shop class (e.g., wallets made entirely from duct tape, back packs reinforced with duct tape).*<br><br>*Potential applications include: space tape, improved "ouchless" bandages, internal surgical bandages, moving microchips or fibers without scratching them, self cleaning adhesive that works anywhere, climbing athletic shoes).* |

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| Slide 16 | *15) The pilot-test teachers highly recommend using this flow chart at the end and/or beginning of each lesson.*<br>*The end of each lesson contains this flow chart that provides an opportunity to show students the "big picture" and where they are in the lesson sequence. The following color code is used:*<br>*Yellow: Past Lessons*<br>*Blue: Current Lesson* |
| Essay Assessment<br><br>Writing Prompt in Student Journal Page: 8–5 | **"In this summative performance assessment, you will demonstrate your learning in this module by responding to the following writing prompt.**<br><br>**Explain how the gecko can adhere to a ceiling. Your written explanation should include the following:**<br>• **Describe (with words and/or labeled drawings) the surface-to-surface interactions between gecko "setae" and a ceiling. Be sure to address the characteristics of both the setae and the surface. Include the shape, number, and size of setae in contact with the surface.**<br>• **Describe the variables affecting adhesion: the surface area, the surface contact, and the type of surface.**<br>• **Explain how a lot of tiny adhesive forces overcome the force of gravity.**<br>• **Describe the electrical forces and their role in gecko adhesion (i.e., interactions of charged particles between atoms of the spatula and the ceiling surface)."**<br><br>*1) Students will draft their written responses as homework and then participate in a peer-review activity during class time. Incorporating peer review transforms the "test" into a writing-to-learn opportunity that engages students in critical thinking with a more in-depth exploration of the content. Furthermore, feedback received through the peer-review process will help students to refine their writing before the final essays are submitted. Through this process, students will also become very familiar with the scoring rubric and expectations for the writing, thereby encouraging them take responsibility for evaluating their own work. Subsequently, the teacher's paper load in this module can be minimized; you may only need to intervene and evaluate the writing when there is a large discrepancy among peer reviews.* |
| Essay Assessment<br><br>Introduction<br><br>Student Journal Page: 8–6 | *2) Instruct students to turn to the Essay Assessment: Demonstrate Your Understanding section of their Lesson 8 Student Journal; this should be the last two pages (8-5 and 8-6). Explain to students that they will show what they've learned throughout this module by responding to the writing prompt.*<br><br>*3) Review the prompt to ensure students understand. The bulleted list provides scaffolding to assist students in fully addressing the prompt. Student responses may include diagrams or images; however, such visuals should be used to reinforce the written explanations not replace them. Each written response should not exceed one-typed page (or one-handwritten page front/back).*<br><br>*4) Invite students to refer to their journals to help them plan their responses. While the assessment is "Open Journal/Notes,"* |

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| | *emphasize to students that their essay responses should not simply repeat journal responses. The journals are intended to help students recall their learning experience. The writing should be in students' own words and reflect a sophisticated understanding of the content.*<br><br>5) *Review the instructional rubric that will be used to evaluate the written responses. The more familiar students are with the expectations of the assessment, the more responsibility they can assume for their own work.* |
| Drafting the Essay | 6) *Instruct students to refer to the rubric as they draft their written responses.*<br><br>7) *Allow one class period for students to respond to the prompts. They may finish the essays for homework.* |
| Peer Review | 8) *Collect students' essays.*<br><br>9) *Devote half of a class period to conduct a peer review using the Peer Review Scoring Guides. Distribute two copies of the Peer Review Scoring Guide to each student.*<br><br>10) *Explain to students that the Peer Review Scoring Guide is based on the instructional rubric, the tool the teacher will use to evaluate their final essays. Therefore, the Scoring Guide will help students give feedback to their classmates. Honest and thorough feedback will enable their classmates to revise their writing before the final assessment is submitted to the teacher.*<br><br>11) *Redistribute the essays to the class. Ensure that everyone has a different paper, one other than their own.*<br><br>**Teacher Tip**<br>You may feel that your students would respond more favorably to an anonymous peer-review process. Assign a special ID code to each student—be sure to keep the master list. Authors will write this ID instead of their name on their paper. Then, ask peer reviews to write both the author's and their own ID on the Scoring Guide. Remind them to label the IDs as either "Author" or "Peer Reviewer" so that the evaluations may be matched to the correct paper at the end of the peer-review process.<br><br>12) *Students should write a "*" in the upper corner of each paper they review. This mark will help keep track of how many times a paper has been peer reviewed; each paper should be reviewed twice.*<br><br>13) *Remind students to write both the author's and the peer reviewer's name on the Scoring Guide so that the evaluations may be matched to the correct paper at the end of the peer-review process.*<br><br>14) *Once students have reviewed one paper, they should return the paper to a designated bin and select another paper to review. Instruct students to turn in the completed Peer Review Scoring Guide to the teacher. The teacher should then glance* |

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| | *at each scoring to ensure that the proper feedback was included and then immediately return the scoring guide to the author. Note: Once a paper has been reviewed twice, as indicated by two "*" at the top of the paper, it should not be returned to the bin to ensure it is not selected/reviewed again. Instead, return it to the author.*<br><br>*15) Allow some class time for students to review the feedback. If students feel there are significant discrepancies (more than a two point difference in scores between two peer reviews), it will be necessary for you to intervene and provide some clarifications. Determine how you would like students to request your intervention. (e.g., If class time permits, conduct one-on-one conferences with students as needed, or ask students to resubmit their papers and accompanying peer review rubrics for your review).* |
| Refining and Evaluating the Final Essays | *16) Encourage students to revise and polish their writing according to the feedback they received. Assign a due date for completing their final draft.*<br><br>*17) On the due date, collect the rough draft, the two Peer Review Scoring Guides, and final draft from each student.*<br><br>*18) Refer to the Anchor Papers for Essay Assessment to assist in evaluating the final essays. (Available in the Appendix A section of this guide). Below is a copy of the instructional rubric.* |

# Instructional Rubric for Essay Assessment

| Criteria | Advanced (4) | Proficient (3) | Partially Proficient (2) | Novice (1) |
|---|---|---|---|---|
| **Writing Style and Mechanics** | • **Concise, clear, and engaging explanations** with **flawless** spelling, punctuation, and grammar. | • **Concise and clear** explanations with **minor errors** that do not interfere with communication. | • **Appropriate writing** format.<br>• Writer does **not appear to have carefully proofread**. | • **Demonstrates little or no attention** to the writing format.<br>• Has great difficulty communicating. |
| **Understanding of Content** | • **Explanations** are complete* and **detailed, demonstrating a sophisticated** understanding of surface-to-surface interactions and forces affecting adhesion.<br>• Writes in **own words** using **common and scientific language.**<br><br>*Responses include answers to all four bullet points in the prompt. | • **Explanations** are **complete*** demonstrating an understanding of surface-to-surface interactions and forces affecting adhesion.<br>• **No clear inaccuracies** or misconceptions.<br>• Mostly writes in **own words** using **common and scientific language.**<br><br>*Responses include answers to all four bullet points in the prompt. | • **Explanations demonstrate a basic** understanding of surface-to-surface interactions and forces affecting adhesion.<br>• **May contain inaccurate** or **incomplete** information.<br>• Writes using **scientific language** only, **not always writing in own words**. | • Explanations are **missing important information.**<br>• **Does not demonstrate a basic understanding** of surface interactions and forces affecting adhesion and/or **contains inaccuracies**.<br>• Writing is **not in own words**. |

NanoLeap

# Appendix A: Anchor Papers for Summative Essay Assessment

**Purpose:**
The anchor papers can assist you in using the rubric to score students' culminating essays. Please refer to the rubric as you read through the various anchor papers.

**Writing Prompt:**
**Explain how the gecko can adhere to a ceiling. Your written explanation should include the following:**

- Describe (with words and labeled drawings) the surface-to-surface interactions between gecko "setae" and a ceiling. Be sure to address the characteristics of both the setae and the surface. Include the shape, number, and size of setae in contact with the surface.
- Describe the variables affecting adhesion: the surface area, the surface contact, and the type of surface.
- Explain how a lot of tiny adhesive forces overcome the force of gravity.
- Describe the electrical forces and their role in gecko adhesion (i.e., interactions of charged particles between atoms of the spatula and the ceiling surface).

Rubric (for Content only)

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| **Understanding of Content** | • **Explanations** are complete* and **detailed, demonstrating a sophisticated** understanding of surface-to-surface interactions and forces affecting adhesion.<br>• Writes in **own words** using **common and scientific language.**<br><br>*Responses include answers to all four bullet points in the prompt. | • **Explanations** are **complete*** demonstrating an understanding of surface-to-surface interactions and forces affecting adhesion.<br>• **No clear inaccuracies** or misconceptions.<br>• Mostly writes in **own words** using **common and scientific language.**<br><br>*Responses include answers to all four bullet points in the prompt. | • **Explanations demonstrate a basic** understanding of surface-to-surface interactions and forces affecting adhesion.<br>• **May contain inaccurate** or **incomplete** information.<br>• Writes using **scientific language** only, **not always writing in own words**. | • Explanations are **missing important information.**<br>• **Does not demonstrate a basic understanding** of surface interactions and forces affecting adhesion and/or **contains inaccuracies**.<br>• Writing is **not in own words**. |

**Key Phrases & Descriptions:**

The following examples have been excerpted from students' essays as illustrations of strong responses to different aspects (bullet points) of the writing prompt.

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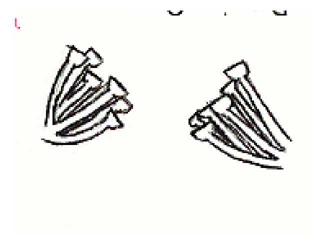
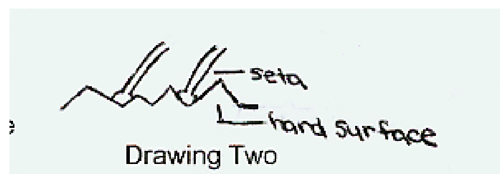
| Describe the surface-to-surface interactions between gecko "setae" and a ceiling. Be sure to address the characteristics of both the setae and the surface. Include the shape, number, and size of setae in contact with the surface. | "Geckos have about one million hair-like seta on their feet. Seta can only be seen with a microscope, because they are near the nanoscale level. Each seta has up to one thousand spatulas branching off the end of it. The gecko can stick to the ceiling because the tiny spatulas get into the bumps on the surface of the surface. Even if the surfaces looks flat, at nano level it is full of bumps resembling small hills (Drawing 2)."    |
| **Describe the variables affecting adhesion—the surface area, the surface contact, and the type of surface.** | "If the gecko walks through dirt and gets his setae and spatulas dirty, it affects how he sticks, but it only takes five steps to clean off all the dirt. This does not work on other adhesive forces like tape. If the dirt increases on tape, the force it takes to pull it up decreases. If there is not a lot of surface contact the adhesive force is not as strong as the adhesive force with more surface contact. If the surface is dirty, it also affects the adhesive force making it not very strong."<br><br>"Adhesion happens when something is compliant. Tape is compliant, because it can fill in the cracks of a surface. A table is not compliant, because it is not flexible and would not be able to fill in cracks. The more surface area the more adhesion you will have, like a bigger piece of tape. The smaller that piece of tape is divided in to, the more surface contact you will have. A big piece might just only touch the top of the cracks, but lots of tiny pieces may touch the sides and the bottom as well. If a surface has lots of cracks in it, the gecko can cling to it because of how the |

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| | spatulas on the setae can fill in and cling to the cracks." |
| **Explain how a lot of tiny adhesive forces overcome the force of gravity.** | "Tiny adhesive forces like Van der Waals attractions are not affected by gravity because the tiny forces are too small to be affected. The electrical forces that allow a gecko to adhere have to be Van der Waals attraction. A gecko's setae has the opposite type of electrical charge than the surface the gecko is adhering to. The attraction between the surface and the gecko setae are not very strong, but with about one million setae the gecko has enough attraction to hold itself to the ceiling with one toe." |
| **Describe the electrical forces and their role in gecko adhesion (i.e., interactions of charged particles between atoms of the spatula and the ceiling surface).** | "But the spatulas fitting into the bumps is not how the gecko sticks. The gecko uses some thing called Van der Wall's. Van der Wall's works at the nano level. How it works is very interesting. The molecules at this level are positively, negatively, or neutrally charged. The positives are attracted to the negative and the neutral. The negatives are attracted to the positives and the neutrals. And the neutrals are attracted to the positives, negatives, and other neutrals. These are charged by electricity. Separate, these currents are weak, but together they can be extremely strong. These spatulas gain more power as they move across the surface. This causes them to gain extreme power and to be very sticky." |

**Misconceptions**:
The following lists some common misconceptions students may have about adhesion:

- Geckos stick with suction cups on their feet.
- Geckos' spatulas "hook onto" the nooks and crannies of the surface.
- Spatulas use micro-interlocking to adhere to the surface.
- The spatulas create friction so that the gecko sticks.

# Anchor Papers Earning a "4" Score

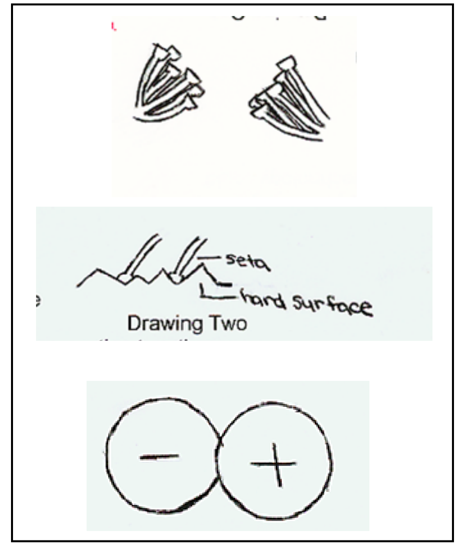
**Why 4? Sophisticated understanding. No content errors.**

4

Geckos have about one million hair-like setae on their feet. Seta can only be seen with a microscope, because they are at the nanoscale level. Each seta has up to one thousand spatulas branching off the end of it. The gecko can stick to the ceiling because the tiny spatulas get into the bumps on the surface. Even if the surfaces looks flat, at nano level it is full of bumps resembling small hills (Drawing 2).

While geckos walk, the microscopic seta brushes against the surface. This force allows the gecko to stick to any surface it is on, including underwater and in many materials. All the tiny forces, the seta, overcome gravity because of the great amount of them. For the gecko to stick, the gecko and the surface have to have opposite charges to attract together (Drawing 3).

The adhesion force which the gecko uses gets activated by sliding of the geckos' seta. This force does not depend on the amount of humidity in the air and will work underwater. The gecko has a type of self-cleaning device that after it steps in dirt and continues to walk, the feet of the gecko will be clean. Each of the geckos' one million seta can hold up to 180 micro Newtons, which means all of them together can hold up to 180 Newtons. Even though the geckos have this many setae, only approximately twelve thousand seta are needed for the gecko to stick on the ceiling, since geckos only weigh 2.2 Newtons.

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4

How can a gecko adhere to the ceiling? The surface of a gecko's foot may fool you. It may look like just ridges and scales, but what it really is, is the little hairs that make up those ridges, and on those tiny hairs are even more tiny hairs that look like little spatulas. The tiny hairs that make up the ridges are called setae. They are about 60 micrometers long. The setae with the spatulas on them fit into the little nooks and crannies on surfaces such as a table or glass. The way these spatulas can do this is because the spatulas are so small they fit into the nooks and crannies on the surface. Also, as the gecko walk across the ceiling it builds up charges. The weak and temporary charges between the spatulas and the ceiling surface are the forces that hold the gecko to the ceiling, because there are so many of these spatulas to holds up the gecko.

But the spatulas fitting into the bumps is not how the gecko sticks. The gecko uses some thing called Van der Wall's. Van der Wall's works at the nano level. How it works is very interesting. The molecules at this level are positively, negatively, or neutrally charged. The positives are attracted to the negative and the neutral. The negatives are attracted to the positives and the neutrals. And the neutrals are attracted to the positives, negatives, and other neutrals. These are electrical forces. Separate, these currents are weak, but together they can be extremely strong. These spatulas gain more adhesion as they move across the surface. This causes them to gain extreme adhesion and to be very sticky.

If the gecko walks through dirt and gets his setae and spatulas dirty, it affects how he sticks, but it only takes five steps to clean off all the dirt. This does not work like other adhesive forces like tape. If the dirt increases on tape, the force it takes to pull it up decreases. If there is not a lot of surface contact the adhesive force is not as strong as the adhesive force with more surface contact. If the surface is dirty, it also affects the adhesive force making it not very strong.

How can adhesive force get equal to or greater than gravity that is pulling the gecko down? In order for a gecko to stick to the ceiling, there has to be the same amount of force both gravity and adhesive. For example, say gravity is pulling on the gecko 10 N. If gravity is pulling on the gecko more than the adhesive, the gecko would fall. It would not matter if the adhesive force were pulling more cause than it would stick better. Therefore, the adhesive forces and gravity have to be the same pull in order for the gecko to stick on the ceiling.

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The gecko has lots and lots of setae to say the least. The setae are able to cling to the ceiling by the spatulas that each setae is divided into. The more surface area you have the better things will stick. The spatulas can be electrically charged making it able to adhere to the crack and ridges in a ceiling. The setae and spatulas are so small that you can only see them with special machines and without machines like that, we would never know the answer to "how the gecko can stick to the ceiling."

Adhesion happens when something is compliant. Tape is compliant, because it can fill in the cracks of a surface. A table is not compliant, because it is not flexible and would not be able to fill in cracks. The more surface area the more adhesion you will have, like a bigger piece of tape. The smaller that piece of tape is divided into, the more surface contact you will have. A big piece might just only touch the top of the cracks, but lots of tiny pieces may touch the sides and the bottom as well. If a surface has lots of cracks in it the gecko can cling to it because of how the spatulas on the setae can fill in and cling to the cracks.

The electromagnetic charge makes the cells on the spatula, be attracted to the surface it is on. The gecko has more seta then it needs because of all the surface area on one spatula. That is why the gecko can stay up on the ceiling for so long and can over come gravity.

The gecko used seta to cling to the ceiling. Each seta is divided into lots and lots of spatulas. The spatulas are made out of electrically charged atoms that are attracted to other atoms that make up surfaces that the gecko walks on. That is the reason why the seta that are on the gecko's feet can hold the gecko on the ceiling or on other surfaces.

# Anchor Papers Earning a “3” Score

**Why 3? *Needs More Detail.* No clear inaccuracies.**

Key:
Needs more detail: gray highlight
3
When connecting the gecko billion of tiny seta find ways into the tiny ridges that can be found at the microscopic levels. The tiny seta, then use its charges, positive and negative to connect with the surface because it’s so small. These tiny feet look like spatulas to help it cover more surface area.

There are many variables that effect whether something would stick to it or not, like surface area. Through experiments we have found out that no surfaces is exactly smooth so by the gecko having a billion tiny seta instead of one big one foot, its able to stick better. For the gecko though you could put it on any surface because unlike other adhesives that stop to stick, if they get wet or something the gecko uses positively and negatively charged atoms.

IF you have a billion little feet each one of those feet isn’t going to really be strong like the big foot, but a billion little feet would start to create a very large force.

When the gecko sticks to the ceiling it doesn’t have to worry about if it is wet, frozen, or anything because it uses some of the tiniest forces of electricity. Each and every little spatulas has two forces, half positive, half negative, and the solid surfaces has thousands of positive and negative forces and because opposites attract the full spatulas is sticking to the surface.

Needs more detail: **Difficult to follow what make a surface more or less adhesive**

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3
This world is full of many amazing creatures and animals. One of these animals is the gecko. The gecko has the ability to adhere to most surfaces at any angle, even upside down. This ability is possible because the gecko has little hairs on the bottom of their feet called setae. These setae are so adhesive that a gecko can lift its own body weight with just one finger. Each seta is made up of several even smaller hairs called spatulas. The effect is similar to a paint brush.

Now the other part that makes a gecko so adhesive is the surface. Some people think that a table top is very smooth, when in fact, if you were to look at the same surface under a microscope, you would notice that it is very bumpy and rough. So now since the spatula-tipped seta are so small, they are able to fit into every nook and cranny of the surface, allowing the contact between the gecko and the surface to be very powerful.

Now this is where a thing called Van der Waal's Force comes into play. Van der Wall's Force is the attraction between two molecules. Since the seta are so small, they are able to feel the weak attraction between the molecules. This allows them to stick to the surface.

But there are many things that my decrease the effectiveness of the adhesion. The amount of dirt on the surface, the texture of the surface, and the amount of contact could all decrease this ability.

Gecko's have opened a gateway for society, now tons of research are being done on gecko's and their adhesive abilities.

**Needs More Detail**: Description of Van der Walls

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3

The gecko has ridge like things on its toes. When you look closer they look like hairs which are called seta and at the end of those they have something called spatulas. The seta is about 20 micrometers longs and the spatulas are about 1 micrometer. The spatula is a triangle shape and they are used to hold the gecko up. There are over one million setae and over 10,000,000 spatulas on a gecko.

There are a lot of things that affect adhesion like water, shape of the surfaces and what you are trying to get to stick. Surface area has to do with adhesion because if there is more surface area, you can hold more up. If you don't have much contact area, you won't stick very good.

Each tiny force on the foot makes up for one big force like gravity because there are a lot of tiny forces. There are over 1 million tiny forces on the feet of the gecko.

On the gecko's foot it is a positive and the surface is negative and they act like magnets and stick to each other. The gecko can pull its seta back to make the force smaller.

**Needs More Detail**: Description of van der Walls or explanation of negative and positive charges.

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# Anchor Papers Earning a "2" Score

**Why 2? Inaccurate, Off prompt, *Needs More Detail, Missing important Information.***

Key:

Inaccurate: Underline Highlight

Off prompt: ~~Strikethrough Highlight~~

Missing Information: gray highlight

2

The way the gecko adheres to the ceiling has been a mystery for many years. We have finally come to a conclusion. The gecko has nano-sized hairs on the bottom of his feet called "setae." Those setae have little things called "spatulas" on the tips of them. The setae fills in all of the bumps and flaws in the hard surface. This makes him stick to all surfaces. The setae look like hairs. The gecko had positive and negative changes on its feet which connect with the neutral charges of objects.

**Needs More Detail:** Surface to surface interaction; How adhesion overcomes the force of gravity; Role of electrical forces and adhesion

**Missing Information:** Variables affecting adhesion

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2
How do geckos adhere to surfaces?

Geckos are one of the most amazing animals because of how they adhere to surfaces. There are many ways the geckos can adhere to a surface. The mechanism a gecko could use is electrical, vacuum, air pressure, friction, magnetism, static electricity, capillary wet adhesion, suction, and micro-interlocking (Velcro). At first I thought the gecko used capillary wet adhesion but we ruled it out because it did not leave a wet trail. Geckos adhere to surfaces such as glass, wood, metal, and many other surfaces. Geckos have hairs called setae on their feet and at the end of those setae are spatulas. The spatulas make the feet have a lot of surface contact. The spatulas have a lot more surface contact because they get into all the nooks and crannies. If it had just the foot, it would not make a lot of surface contact compared to how much contact the spatulas make. The spatulas are dragged across the surface; they act like as if they were a liquid. Geckos have enough surface contact that it only needs one feet to hold on to its surface. Setae look like little strands of hair. The gecko has about 100,000,000 – 1,000,000,000 spatulas and about 1,000,000 setae. So many tiny spatulas over come the force of gravity because the setae has such great surface contact. The spatulas and the ceiling surface are both neutrally charged things so they both attract. It is not all that clear and concise on how geckos stick to the ceiling, but after this unit I really began to understand the way a gecko adheres to surfaces like wood and glass.

**Inaccuracy:** Unclear which of the adhesion mechanisms were discarded; pretty sure how the gecko adheres

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2
Geckos can adhere to a ceiling

Geckos have tiny hairs call setaes and at the end of setaes is a suction cup like called spatulas. They need 12,222 setas to hold a gecko up and they have a million setas on a gecko. Also they have 1 billion spatulas. They are what holds them up the ceiling. The spatulas get in the nooks and grooves of surfaces that is why they stay up. Geckos have a attractive force which is called van der Waal's attraction. Also a gecko has 180 micro newtons of force. It is a mystery how geckos have consistent electrical force, regardless of speed, humidity, underwater. A gecko can walk without falling. Also, their feet are always clean because they clean themselves.

**Inaccuracy:** Spatula is not a suction cup.

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NanoLeap

# Anchor Papers Earning a "1" Score

**Why 1? Inaccurate, Off prompt, *Needs More Detail, Missing vital Information.***

Key:

Inaccurate: Underline Highlight

Off prompt: ~~Strikethrough Highlight~~

Missing Information: gray highlight

1

How does a gecko adhere to the ceiling?
The gecko adheres to the ceiling with its setae. Setae are tiny hairs on the foot. At the tip of the setae are shaped like little spatulas. There are tiny hairs that are the tips of the setae. Then, there's smaller hairs on that tiny hair. There are so many little hairs that they fit in the bumps and crevices. Then the molecules of the surface attract making a charge. So that is how they can walk on the ceiling.

**Missing Information:** More detail is needed to explain surfaces, electrical forces and their role in adhesion, and variables affecting adhesion.

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1
The gecko can adhere to a ceiling because of the many ways nano fibers on their satae. The Setae consists of millions (maybe even more) tiny hairs that produce adhesion to a molecular level.

**Missing Information:** More detail is needed to explain surfaces, electrical forces and their role in adhesion, and variables affecting adhesion. Doesn't really fully answer the prompt.

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1
How adhere sticks to ceilings is that geckos have seta. Seta are tiny hairs that help geckos stick to ceilings. One piece of seta is about 20 Mm. On every tip of a seta looks like a spatula. A ceiling is flat and sometimes smooth a seta is like a suction. It traps the little places so it can stick on things.

The surface area is bumpy and the gecko could fall because ~~the ceiling could have the little white foam things and it could just fall cause the one could loosen up and the pieces would fall.~~ The adhesive forces the more of a chance to hold onto the ceiling the less forces the more of chance falling from the ceiling.

The gecko use molecules like Vander attractions Vander waals forces.

NanoLeap

# Appendix B: NanoLeap Physical Science Vocabulary for Lesson 8

**Atom**
One of the minute indivisible particles of which matter is composed. It is made up of a nucleus, composed of protons and neutrons, and electrons that orbit the nucleus.

**Electron**
An elementary particle consisting of a negative charge that orbits a nucleus of an atom

**Electron cloud**
1. The system of electrons surrounding the nucleus of an atom
2. A region in which electrons surrounding the nucleus of an atom are most likely to be found

**Nanotube**
A microscopic tube whose diameter is measured in nanometers: These are almost always carbon nanotubes, referring to the wires of pure carbon that look like rolled sheets of graphite.

**Negatively charged**
Having more electrons than protons, and having a lower electrical potential

**Nucleus**
The positively charged central portion of an atom that comprises nearly all of the atomic mass and that consists of protons and usually neutrons

**Positively charged**
Having more protons than electrons, and having a higher electric potential

**Proton**
An elementary particle identical to the nucleus of the hydrogen atom that, along with the neutron, is a constituent of all other atomic nuclei, and carries a positive charge numerically equal to the negative charge carried by an electron