# The Fusion of Biology and Materials Science through Hands-On Activities and Demonstrations

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**Abstract**
This module presents several hands-on demonstrations and activities that introduce and explain basic concepts of biomimetics. Emphasis is on understanding concepts of scale, laboratory instrumentation, logical reasoning, and imaging materials. The demonstrations and hands-on activities are chosen and geared to support teacher efforts to meet the requirements of the state's Standards-of-Learning. The activities presented can be tailored to suit regular classes and after school enrichment programs (1 hour).

The hands-on demonstrations and activities are presented below as three separate modules: Measuring and Scaling, Images of Surfaces, and Biomimetics.

## I. Measuring and Scaling

**Objective**: The exercises and presentations in this module are intended to help students understand the concept of measuring at different scale lengths, know and appreciate different biological organisms and man-made objects that exists at various scale lengths, and develop a "feel" for the various scale lengths.

**Student learning objectives**: The students will be able to

- Demonstrate what various scale lengths are and why they are used
- Explain why it is useful to relate objects to the various scale lengths
- Develop a "feeling" for what the various scale lengths are
- Show how scientists measure on particularly small scales

**MatEd Competencies Covered**

1A Carry out measurements of dimensions and of physical phenomena
1C Demonstrate laboratory skills

**Keywords**: Measurement, scaling
**Type of Module**: Laboratory exercise, discussions
**Time Required**: One period (or less)
**Pre-requisite Knowledge Required**: Basic understanding of the metric system
**Target Grade Levels**: Upper Elementary, Middle school

**Equipment and Supplies Needed**:
Computer with Internet access, scissors, meter sticks and/or scales with small divisions, a magnifying glass, a school microscope, 10 identical books (or other identical, stackable objects of the same size), human hairs, and dead bugs.

**Curriculum Overview and Notes to Instructor**:
The nature of these exercises lends them to being tailored to suit your target audience's grade level. Emphasizing the biological aspect helps because students are typically more in tune with nature than materials science. This makes for a natural bridge that helps their understanding.

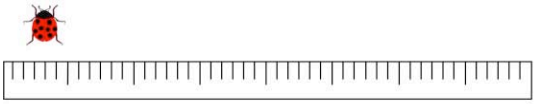
Please refer to the first section of the PowerPoint presentation for images for this section.

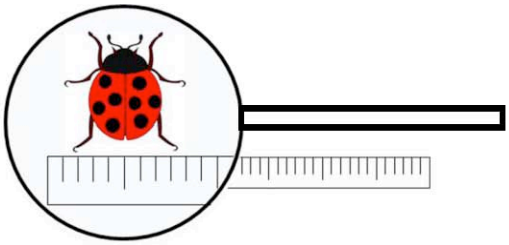
**Procedure:**
a) Scale Wheel
For this exercise, the students cut out and construct a scale-wheel like the one shown at the end of this module. The two parts are prepared in advance by the instructor and the students will only need to use scissors and a punch to cut out and assemble the wheel. (You can save time by having everything cut out in advance and the students simply assemble it.)

Once students have the wheel you can lead a discussion about length scales that are involved. Ask the students to give examples of objects that are on the order of the size listed on the wheel. As the scale gets smaller, it becomes more of a challenge so adjust your questions appropriately. Since the powers of ten are involved, use 10 identical books, (or other similar type set of identical objects) to help in the explanation. Stack the ten books and measure the height with a meter stick. Measure one book and then show how this is 1/10 the size. Work other examples of fractions and help students develop a "feel" for smaller objects by using the concepts of fractions and powers of ten. Use human hair as an example to reinforce this concept. Use an SEM image of a human hair (see ppt) to show students why the feeling for a fractional amount is important by pointing out that you can see a human hair (~ 100 μm) but certain features are about 1/10 as small and cannot be seen. Have students look at hairs and let them explore putting groups of hairs together to understand the concept of fractions and scale.

b) Measuring on smaller scales

This exercise has the students measuring small objects (in this case dead insects). The students can easily measure the overall size of the insect and, depending on the insect, the smaller parts of it. However, to accurately measure, the students will use a magnifying glass to see the smaller parts more clearly as shown in the diagram below. In order to obtain accurate measurements, you can lead a discussion about the divisions on the meter stick and what they would need to use instead of a meter stick.





c) Instruments and measuring

This exercise involves a discussion of the various types of instruments used to measure on small scales. Starting with the meter stick example above, a natural follow up is to use a microscope. Students will most likely use a basic microscope found in the biology lab, so having one (or more) of these on hand would be useful. Have the students look at parts of the insect(s) using the microscope. Discuss with them the advantages and disadvantages of using the optical microscope and how sizes can be measured (or determined).

Continue the discussion of microscopes and microscopy by introducing the other types of instruments available to scientists and how each one can measure to a different scale. Pictures of typical instruments can be shown along with typical images that are obtained from each one. Particularly effective for students are biological images. Show these images and relate what they are seeing to a particular scale length. (Incorporate the scale-wheel in these discussions as it helps students relate what's being observed to what types of instruments are used to make the observations.)

## II. Images of surfaces and structures

**Objective**:
This is a continuation of the exercise on scaling. The students are shown various groups of two similar images (at the macro- and nanoscale) and are asked to guess or describe what the images represent. Each set of images is then discussed on composition, materials, properties, and possible applications. The discussion could be extended or compressed based on students' level and time afforded for this exercise. We show images of thin films, nanoparticles (silica sphere, polystyrene, etc.) as well as biological samples (lotus surface, butterfly wings, etc.).

**Student learning objectives**:
The main objective of this exercise is to emphasize the importance of scaling. The students will be able to

- Explain the difference between macro- and micro-/nano- scales
- Explain the importance of using appropriate instruments for imaging and characterizing surfaces and structures
- Understand the concept of biomimetics

**MatEd Competencies Covered**

1A Carry out measurements of dimensions and of physical phenomena
5B Demonstrate knowledge of chemistry fundamentals
7K Compare thermal, physical, and other properties of materials

**Keywords**: Scaling, images
**Type of Module**: Discussion, PowerPoint Presentation
**Time required**: 15 – 30 minutes or one period
**Pre-requisite knowledge**: Familiarity with length scale
**Target Grade Levels**: Upper elementary to introductory college

**Equipment and supplies needed**:
Computer (Power Point), projector, Internet access. Selected similar images of object, structures, and surfaces from macro- and micro/nano –world for side-by-side comparison (see ppt).

**Procedure:**
Please refer to the first section of the PowerPoint presentation for images for this section. The students will be reminded about the scaling and the various levels. Our eyes see at the macro scale and upper level micro scale. The general perception might be that at lower scale levels everything is flat. The main goal of this exercise is to teach students that specialized instruments help us "see" features at the micro- and nano- scales and that complex structures exist at these scale levels. To illustrate the similarities between shapes and structures of the various scales they

will be viewing a collection of similar images side-by-side. For example they are shown the desert and a copper surface, corral/corral of iron atoms on copper surface, cabbage coral reef and MoS2 nanoflower, pentacene film and divinity dessert, gold film and dried mud, etc. The instructor could use the included PowerPoint presentation for illustrations and expand on these depending on the allowed time and the educational level of the class. As appropriate, applications of the fabricated films and structures can be discussed: sensors, basic knowledge, filters, etc., for which more details are included in each of the images of the Power Point presentation.

**References**

1. Please see references noted in the Power Point for the various images.

## III. Biomimetics

**Objective**: This module is designed to introduce the basics of biomimetics and is related to the scaling module in which various surfaces were shown. The students are told what biomimetics is, why scientists are interested in imitating nature, and what are some practical applications already in use. A set of images that compare the natural phenomena and the man made ones are shown to students and brief explanations are given in class. Each set of images is discussed on composition, materials, properties, and possible applications. The discussion could be extended or compressed based on the students' level and the time afforded for this exercise. In this module we show images of Lotus leaves and self-cleaning surfaces, Burdock plant and Velcro, nacre and montmorillonite/polymer films, butterfly wings and opals and photonic crystals, including inverse opals. Other examples can be added to the module depending on the allotted time.

**Student learning objectives**: The main objective of this exercise is to introduce biomimetics and to show examples of biomimetics applications. Students will able to

- Define biomimetics
- Explain the importance of biomimetics in applications useful to humans
- Give examples of biomimetic applications

**MatEd Competencies Covered**

2B Demonstrate proper use of units and conversions
3C Apply technical software to practice
6D Apply concepts of light and sound
7J Demonstrate how materials properties are used in engineering design
7M Describe the general nature and behavior of emerging materials technologies

**Keywords**: Biomimetics
**Time required**: 15 – 30 minutes or one period
**Pre-requisite knowledge**: Familiarity with length scale, applications of materials in everyday uses
**Target Grade Levels**: Upper elementary to introductory college

**Equipment and supplies needed**:
Computer (Power Point), projector, Internet access. Selection of samples from nature and manmade that have been implemented as practical applications, for example opals, burdock burrs, columbine leaves, Velcro, nacre shells (see ppt).

**Procedure:**
Students are asked about the word biomimetics. What do they think it means? Then, they will be given the formal definition (see below) and, using the PowerPoint, they are shown several examples of applications and explanations on how they work. In our example we have lotus leaf

and self-cleaning surfaces with applications, Burdock plant and Velcro, mother of pearl and clay/polymer coatings, butterfly wings, opals, and photonic crystals.

Biomimetics = the development of a novel material or product based on an idea, principle or mechanism borrowed from nature.[1]

1) Before the class presentation collect items to be shown as examples such as burdock plant burrs and Velcro, several seashells, butterfly wings or feathers, opals.

2) Introduce biomimetics: definition, motivation for "copying" or mimicking nature. Explain that although the natural processes, structures, and phenomena have existed for a long time, recent advances in instrumentation and materials (especially through nanotechnology and nanomaterials science) have allowed for rapid and significant progress in biomimetics. Then discuss examples of biomimetics applications as follows using as reference the Power Point slides included.

3) Lotus effect and self-cleaning surfaces example. The leaves of Lotus plants (and other plants such as columbine, tropaeolum, and cane)[2] possess a naturally self-cleaning, water repellent surface. The leaves exhibit a superhydrophobic property, which means that the advancing contact angle the water beads form with the surface is greater than 150° and the hysteresis angle is very low. In the Lotus leaf this is due to a combination of the roughness created by built in micro- and nanostructures (cuticles or microasperities) and by their waxed surface.[3] The papillae, as shown in the Power Point figure, are 10 micrometers in height and 10 micrometers in width and they have waxed surface. The contact angle that the water forms with the surface is 170° and when water falls on the surface it forms beads that roll off removing any dirt or other particulates present on the surface. Thus, the plants protect themselves from fungus growth and other pathogens and are able to stay clean for the photosynthesis process to take place.

   Applications of these surfaces include water-repellent paints that contain microbumps (Lotusan), fabrics, coatings for car windows or for sensitive optical instrumentation, and other self-cleaning surfaces. There are various ways to achieve a lotus leaf type of surface: by applying fluorochemicals on structured surfaces or by using compositions that already contain microparticulates, such as Teflon. The coatings can be applied by spraying or painting, or by layer-by-layer deposition.[4] The two examples shown in the Power Point are (on the left) a plastic surface structured by using an ultrafast femtosecond laser[5] and (on the right) a thin film made by layer-by-layer deposition of polyelectrolytes (polyallylamine hydrochloride) (PAH) and poly(acrylic acid) (PAA)) and 50 nm SiO2 nanoparticles4.

4) Burdock – Velcro example. Use the images in the Power Point or from the references provided. Burdock is a biennial plant, a thistle.[6] It is easily recognized by the prickly heads that can catch on clothing, hair, or fur. These hooked burrs allow for the spreading of seeds.

Students would be interested in other uses of the plant,[7] how the idea for Velcro[8] came about, and its name. Velcro is used not only in clothing and bag fasteners but also has many aerospace applications.[9] Students can look through a microscope (even a magnifying glass works) to identify and compare the hooks-and-loops in both the plant's burrs and the Velcro. Regarding Velcro, discuss its advantages (easy to use – children, safe, maintenance free, noisy) and disadvantages (noisy – lately some improvements, can damage clothing, accumulates hair and fur).

5) Nacre shell – ceramics and hard coatings example. Use samples of nacre of abalone shell and explain the uniqueness of this composite.[10] It consists of organic and inorganic components in which soft material layers such as proteins or fibers (on the order of 1-100 nm) provide the structure or glue for binding the ceramics layers (with specific shape and orientation). Nacre shell is strong and tough, has a Young's modulus of 70 GPa, and a high modulus ceramic phase (~ 500 nm thick layer of calcium carbonate – aragonite) that provides stiffness. The organic phase assures the toughness and is provided by proteins. The two main advantages of building ceramics and hard coatings through this natural model is reduction in pollution and low-cost. The advancement of ceramic technologies and the emergence of nanotechnology (nanopowders) have created possibilities for development of new and improved hard coatings and ceramics. One example is the layer-by-layer deposition process that allows for successive deposition of clay particles and polymers that mimic the structural layer of the nacre shell.[11] This structure has been termed as the "brick - and - mortar" and such thin films (hundreds of nm thickness) made with poly(diallyldimethylammonium chloride) (PDDA) and montmorillonite clay particles have been measured to 10 GPa Young modulus values. These types of coatings have numerous applications in military (light body armor), automotive, marine, and aerospace industries, buildings, medical equipment, and in the field of nanotechnology.

6) Opals and photonic (band gap) crystals example. Students will be shown examples of opals and butterfly or beetle wings and will be given a short description of their specific properties. Opals are made of amorphous silica spheres and exhibit various colors based on the water content (3% to 21% of the total weight). The hydrated silica spheres (150 – 300 nm) are packed in hexagonal or cubic close-packed lattice (therefore, this example could also be related to the spheres packing exercise). Opals are natural photonic crystals meaning that they are periodic optical nanostructures (alternating high and low dielectric constant regions) that, through diffraction of light, influence the motion of propagation of electromagnetic waves (light). That means that based on the pattern of the index of refraction within the crystal, certain wavelengths will not be allowed to travel through the material. Other examples of naturally occurring photonic crystals include, but are not limited to, beetle scales, polychaete worms, fish scales, and Morpho butterflies[12] (see example in Power Point slide). These biological forms have specific colors not due to pigments but due to the nanostructures that make the wings or their bodies, as is the case for Brazilian beetle.[13] The structure of the chitin scales of this beetle is very similar to that of diamond giving the scale

an iridescent green light. (This module could also be tied in with the various forms of carbon presented in this paper). If available, some of these examples (opals, butterfly wings) could be given to students to handle and looked at with a microscope.

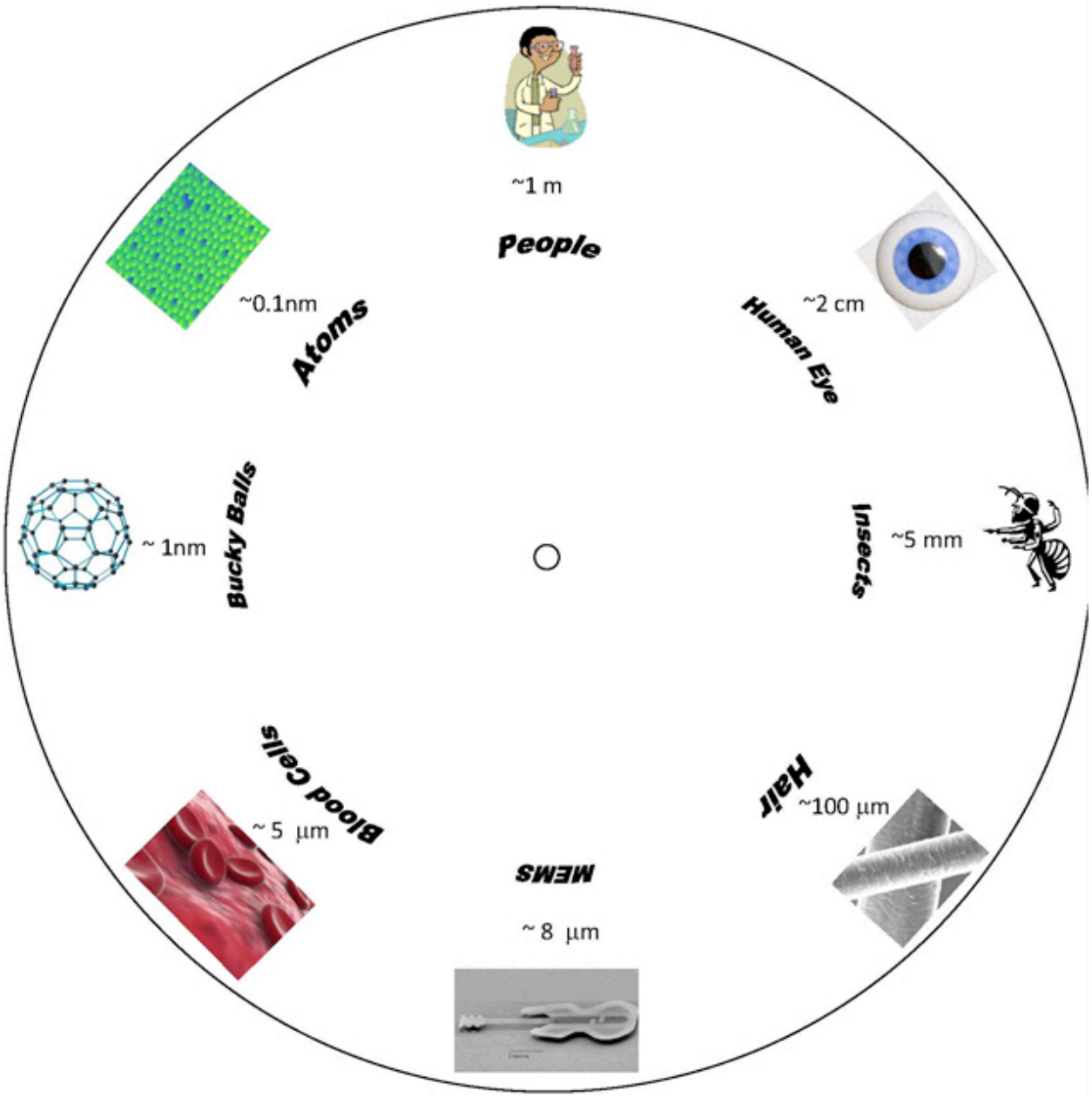
Man made photonic crystals have numerous applications that include reflective coatings, paints, textiles, light emitting diodes (LED), computer chips, and laser materials. The structures can be formed through various techniques, such as thin layer vacuum deposition, self-assembly, colloidal sedimentation, lithography, and etching, as is the case for inverse opals.

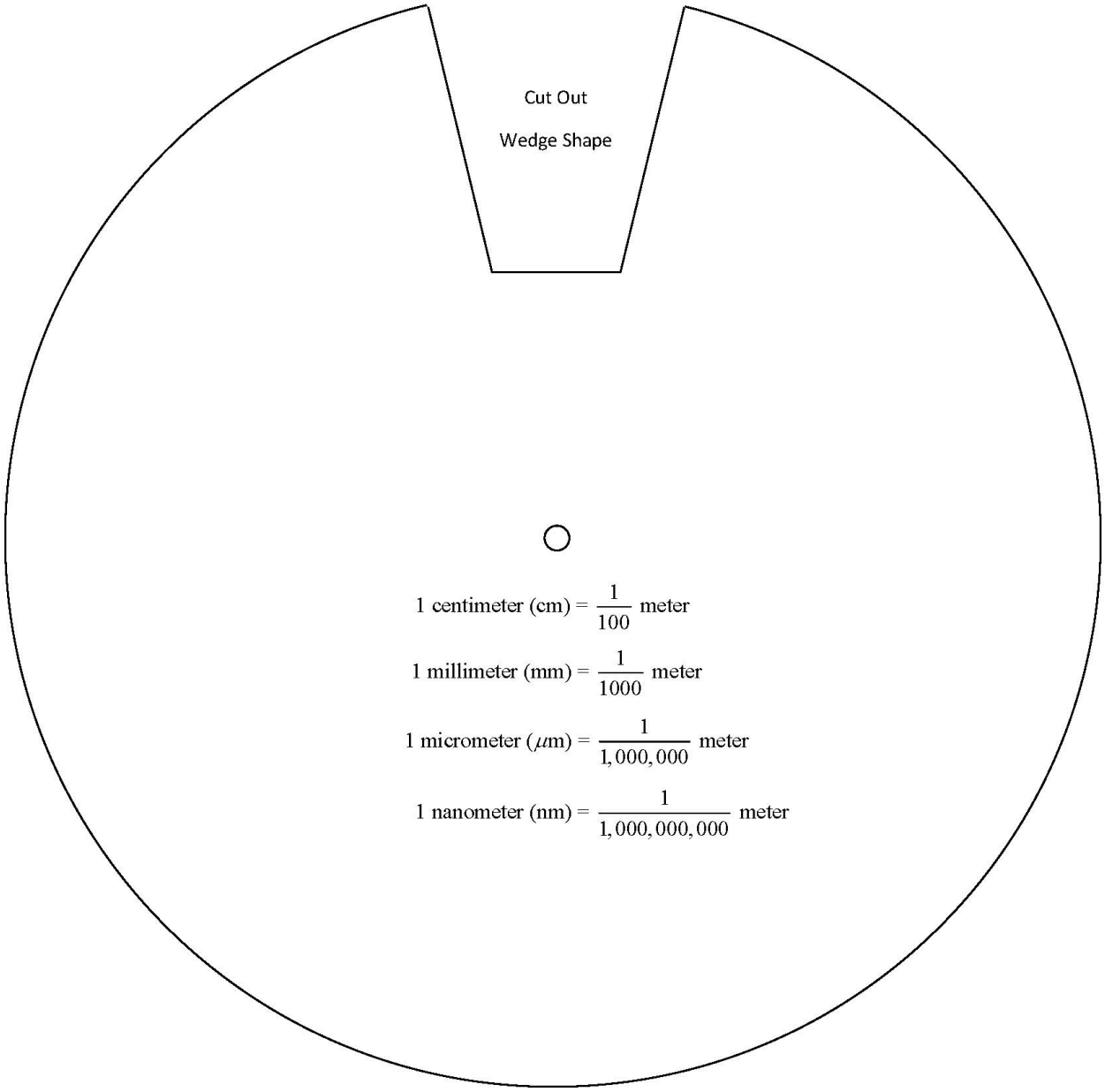
These are only several examples of the many that could be shown to students for the introduction of biomimetics. One can select many other examples for various applications based on surfaces, functionality (gecko feet for "stickiness", sharkskin denticles to reduce drag), structures (windmill blades based on humpback whale flippers), etc.

**References**

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# A Sense of Scale






$$1 \text{ centimeter (cm)} = \frac{1}{100} \text{ meter}$$

$$1 \text{ millimeter (mm)} = \frac{1}{1000} \text{ meter}$$

$$1 \text{ micrometer } (\mu\text{m}) = \frac{1}{1,000,000} \text{ meter}$$

$$1 \text{ nanometer (nm)} = \frac{1}{1,000,000,000} \text{ meter}$$