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The Relative Nature of Size in Biological Sciences: Let's Start Small and Work Our Way Up

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Introduction

Does size matter? This question can either be an indication of some profound cutting edge concept or the beginning of a really bad joke. In this particular case, we shall explore the former and perhaps end this discussion with some form of the latter. Nanotechnology is a big word that is used to describe a science which deals with things that are really, really small. Engineer Wendy Crone from the University of Wisconsin-Madison explains, "Nanotechnology means working at the scale of molecules. When you put nano in front of meter that means that's a billionth of a meter. Nanotechnology is already starting to affect our lives, and it's anticipated that over the next 20 years it's going to have major impact on everything around us."

Why is nanotechnology perceived to be the next "big thing"? The applications for nanotechnology, also referred to as nanoscience, are numerous and far-reaching. Research is currently being conducted in areas as diverse as cancer treatments, self-cleaning windows and toilets, water purification, and cosmetics. In this unit, I want to introduce to my students a concrete concept of size scaling and how size relates to the structure and function of living organisms. In addition, I will explore the science of nanotechnology and the various applications that are available today as well as the potential for future applications.

Student Background

This is my eleventh year as a high school science teacher. I received an undergraduate degree in Biology and worked in food laboratories in quality control and research and development for about 10 years; then I went back to school, earning a master's degree in education and became a science teacher. I have taught at my current assignment for 8 years. My school has a population of about 1,800 students, approximately 54% on free and reduced lunch. The student population is 25% Caucasian, 49% African American, 5% Asian, 16% Hispanic, 1% American Indian, and 4% Multiracial students. We have a large population of EC (exceptional child) students, an IB (International Baccalaureate) program, and offer Honor's and AP (Advanced Placement) programs. We are a diverse school population, which I think makes our school a good atmosphere for preparing them for real world experiences.

One of my most rewarding teaching experiences has been working with my ESL (English as a Second Language) students in the Sheltered Instructional Observation Protocol (SIOP) Program. This program is designed for students that have limited English language proficiency and have recently come to the United States from their native country or are living in households where their primary language is not English. One of the main focuses of SIOP is to provide the ESL students with a "sheltered" environment as they transition into American culture from their native country. I try to achieve an atmosphere of safety and inclusion by establishing early on that each member of the classroom has the right to learn and express his or her own opinions and we must be respectful of each others pacing and style of learning. SIOP stresses the effectiveness of differential instruction, cooperative learning, and the use of multiple intelligences. These students are creative and have rich experiences to contribute to the class, but they tend to be shy when reading aloud or speaking in front of their classmates. I feel that the first section of my unit, which emphasizes mathematics and the metric system, will work well because they tend to do well with these subjects. The second part of my unit will also be good for these students because they will be able to research and present their work while expressing their own unique creativity by generating fictitious monsters.

Another important group of students is my Honor's Biology Class. This class consists of 28-30 students ranging in grades from 9-12 and age's 14-17. These students are ethnically diverse: Multi-racial, White, Black, Asian, and Hispanic. Most of the students are selected for this class based on previous math and other test scores as well as teacher recommendations based on their status as AG (academically gifted) and/or participation of the IB (International Baccalaureate) Program. This class is vocal and social, so they enjoy having discussions and sharing their opinions. These students benefit from any additional rigor and challenge incorporated into the standard curriculum, which will provoke them to think, reason, and make connections with what they are going to be learning. The curriculum in this unit will be beneficial for this group because it will encourage them to use inquiry by requiring them to not only generate their monsters or creatures base on the rules of scaling and physics, but it will allow them to critique each other, which will open up room for continued higher level thinking. The next component which will benefit my honor's students will be the introduction of technology, which is something that out school district is strongly advocating for the next school year.

Rationale

My purpose of creating this unit is to introduce several basic concepts in Biology as they relate to size as well as introduce some practical applications of nanotechnology as it relates to the lesson I already teach on biotechnology. I frequently have had difficulty in assisting my students in understanding the concept and relationship of size, especially as it relates to the metric system specifically, and size relativity of all living organisms in general. Many of my students are unaware of the most basic comparisons, such as the conversion of objects from millimeters to meters. They have difficulty with the mathematics of the conversion, and they likewise have difficulty conceptualizing the relationship between what is considered large and what is considered very, very small. I realize that if they have difficulty relating to measurements, which represent macroscopic objects, then it is understandable that they have even more difficulty with visualizing and relating to the vast microscopic world.

I am also excited about introducing my students to the science of nanotechnology. During the course of the semester, I discuss with my students various technologies—including biotechnologies used by scientists in the field of Biology such as recombinant DNA, cloning, and genetic engineering. During our discussion of these topics, I also want to relate the nature of what nanotechnology is and some of the practical applications that are being developed and utilized at this current time. Upon the completion of this unit, I want my students to be able to recognize these concepts and be able to apply this knowledge effectively as we discuss the structure, function, adaptation, evolution, and interconnectedness of all living organisms in our biosphere throughout the entire course. As a result of teaching this unit, I want to be able to introduce some of the models and concepts which not enhance what we will be covering in this course, but will form background knowledge for the courses my students will take after Biology such as Chemistry, Physics, Physical Science, and Anatomy.

Unit Course Objectives

This unit is compatible with the North Carolina Course of Study in that it supports the implementation of unifying concepts in science. The first unifying concept is that students need to able to relate systems, order, and organization. Upon completion of this unit students will be able to relate organisms of various sizes and their structure to function in their respective habitats.

The second unifying concept is that students will be able to construct and interpret evidence, models, and explanations. By the end of this unit, students should be able to interpret what they read and class discussions concerning sizing and scale and be able to construct their own models. Students will then be expected to present and defend their constructs to their peers, who will also rate the models and provide feedback based on what they have learned from the unit activity.

The third unifying concept is that students should be able to understand the importance of consistency, change, and measurement throughout science. This aspect of science also includes the necessity in science for the ability to understand the concepts of accuracy, rates, and scaling. In this unit, students will become aware of the affect that size plays in an organism s ability to move, obtain energy, carryout transport, and respire—all of the characteristics that support living systems. This information will become invaluable when we are discussing taxonomy and as we compare and contrast Monerans, Viruses, Protista, Fungi, Plants, and later Animals. The students will have a better foundation for background knowledge and will be better equipped to make inquiry associations concerning the specific characteristics of each Kingdom as to how the differ and how they are also similar.

The fourth unifying concept is that of evolution and equilibrium. Students need to understand that evolution is change over time and that organisms tend to adapt with their environment until an equilibrium is reached or until the need for further adaptation. Upon completion of this unit, students will be able to understand why organisms are structured as they are relative to their size, and how their structures must change in relation to any change of size. If an animal gets larger, they must develop more efficient means to metabolize energy, get rid of waste, support added mass, and so forth.

The fifth and final concept of the North Carolina Course of Study is that students need to understand the relationship between form and function. Throughout this unit, students will be observing how form relates to function—for example, why small birds have smaller, hollow wings to assist them in becoming more aerodynamic, and why elephants have much thicker, denser bones in order to support their increased mass.

In the culminating portion of my unit, I will present the science of nanoscience and some of its practical applications. I will present actual research and experiments being conducted with nanoscience and how these studies are being implemented in the biological sciences. This part of the unit will relate to Goals 1 and 4 of the North Carolina Standard Course of Studies in that the student will be able to analyze reports of scientific investigation and form an informed, scientifically literate viewpoint as well as develop an understanding of the unity and diversity of life.

Unit Background Part One- What is the significance of size?

As stated in my rationale, my students tend to have difficulty in relating the proportionality of size, especially when presented with items that are very small. In the first part of my unit I will present to my students items that they can identify with and visualize, such as a grain of rice or a crystal of salt, and ask them to relate those things proportionally to items they cannot visualize such as bacteria, viruses, and nanoparticles. John Tyler Bonner in his book, *Why size matters: From Bacteria to Blue Whales* states, "That the role of size has been to some degree neglected in biology may lie in its simplicity. Size may be a property that affects all life...size is an aspect of the living that plays a remarkable, overreaching role that affects life's matter in all its aspects. It is the universal frame from which nothing escapes." Before I can convey to my students the understanding of biological structures and functions in living organisms, I must first present them a functioning framework of measurement and scaling.

The first step toward developing a concept for how big nanoparticles are is to acquaint students with the skill of accuracy in measurement and the principals of the metric system in order to develop a working frame of reference. Nanotechnology deals with the smallest particles at the atomic level: atoms and molecules. A nanometer is one billionth of a meter, 0.0000000001 or 10^{-9} meters. The term nanoscale refers to objects which are 1-100 nanometers in length. There are several good websites that can be searched which will assist in visually representing "the power of 10." This will allow students the opportunity to relate an object that is approximately a meter to a particle that range of a nanometer. Refer to the appendix which follows for a list of specific websites used in this particular unit.

After students have an understanding of measurement and size relativity, the next concept to introduce is scaling in biology. To understand scaling, the students must be able to directly apply what they have just learned about relationships in size with a new concept called allometry. Allometry is defined as the measurement of the rate of growth of a part of an organism relative to the growth of the whole organism. Scientists have studied the relationship of size with structure and function of living organisms, since even before da Vinci drew the *Vitruvian Man*. Physicist Geoffrey West states, "Life is the most complex physical system in the universe. Beyond natural selection, genetic codes, and the like there are hardly any general principles or laws that we know that it obeys. Scaling laws are the exception. These are quantitative laws and remarkably, they are absurdly simple given you are dealing with the most complex of systems." The idea of scaling relates to the concepts that are typically taught in biology class when introducing rates of diffusion and cell size growth.

Here is a simple example of allometric reasoning. For a cube, one can determine the cross-sectional area of the cube, measured in centimeters squared (length x width), and the volume (length x width x height), measured in centimeters cubed. For cubes of length 2 cm and 3 cm, one finds that the cross-sectional areas are 4 cm squared and 9 cm squared and the volume is 8 cm cubed and 27 cm cubed, respectfully. From this observation, it is clear that volume increases at a much faster rate than area or surface area. I usually demonstrate this concept in my class by having them observe a balloon. The material of the balloon is fairly thick and opaque before inflation. As the balloon is filled with air, I ask them to observe how the balloon becomes more and more translucent to transparent. The material that makes up the balloon represents the cell membrane or surface area and the air being introduced into the balloon represents the increased volume. The students are able to conclude at the end of this activity that if you continue to add to the air inside the balloon and the volume inside the balloon increases, it will eventually burst (or lyse in the case of the cell) because the surface area or material of the balloon cannot accommodate the ever-increasing volume. This observation is crucial for living things because it suggests that as organisms increase in size their volume (mass) increases more rapidly than other features, which affects many physiological relationships such as the ability to diffuse gases (such as oxygen and carbon dioxide), food, wastes, enzymes, and many other chemical processes.

This observation provides an opportunity to discuss with students the relationship between structure and function in living things. An amoeba, which is unicellular, does not need the same complex physiological system as say a multicellular organism like a goldfish. The goldfish has much more surface area to mass ratio in addition to highly specialized organ systems; it requires a much higher metabolism in order to carry out required bodily functions. The amoeba, on the other hand, is much simpler as it seems to randomly "blob" around in the water with the use of its pseudopodia for movement and ingestion nutrients. The amoeba does not have specialized organ systems because food, water and waste can pass through by the means of simple transport called endocytosis and exocytosis (or phagocytosis and pinocytosis). Even though a goldfish is relatively small compared to us, it is large enough that the transport of food, water, and waste requires more complex means than the amoeba. The principle of scaling is crucial in understanding and being able to predict the needs involved in supporting an organism s metabolism.

Another factor involved in scaling is force. Haldane in his essay "On Being the Right Size" relates, "You can drop a mouse down a thousand-yard shaft; and, on arriving on the bottom. It gets a slight shock and walks away...A rat is killed, a man broken, a horse splashes" This introduces the concept of the weight-strength ratio; larger animals have bones which must be designed thicker and denser to accommodate their increased mass. That is why birds have smaller, hollow bones whereas rhinos are sturdier. LaBera explains, "The strength of a bone is approximately proportional to its cross-sectional area; this is a simply another way of saying that there is a maximum mechanical stress, or force per unit area that a bone can withstand. The load the bone must bear is proportional to the mass of an animal. With an increase in size but no change in shape, the load on the bone will increase in proportion to the increase in volume (which changes as length cubed), but the cross-section area of the bone will only increase as length squared." Eventually, if scaled proportionally, an animal's bones will break under its own weight. This answers the question—Is there a limit to how large an animal can get? The answer as it applies to the strength ratio is: yes. This factor could also apply to the fact that large animals like the dinosaurs are now extinct. Students are going to use concepts in this unit to determine the feasibility of the size and structure of very large or very small creatures as they begin thinking about constructing their monsters.

There is yet another set of forces that act upon organisms based on their size: fluid mechanical forces that are approximated with what is called the Reynolds number, discovered by engineer Osborne Reynolds. Reynolds found that you can characterize the effect of fluids on objects by examining the relationship between inertial forces and viscous forces. For small organisms and cells, which have a low mass and therefore low inertia, the effect of fluid viscosity is much greater than for larger organisms. Bonner relates, "Imagine a man swimming in a liquid that produces the same low Reynolds number as would exist for his own sperm, It would be like trying to swim in thick molasses in which one was not allowed to move one's arms or legs faster than the hands of a clock." Organisms such as euglena or cells such as sperm have very low inertia: if their flagella or cilia stop moving, they in turn stop immediately- they live in a low Reynolds number environment. Larger organisms such as a human swimmer completing laps in a pool will continue to move forward some distance if he or she discontinues propulsion: they are swimming in a high Reynolds number environment. The Reynolds number scales directly with size: all other things being equal, smaller objects live in a lower Reynold's number environment than larger objects. This concept further illustrates how structure and function plays a crucial role in the design of an organism.

Background Information Part 2- Nanotechnology and its applications

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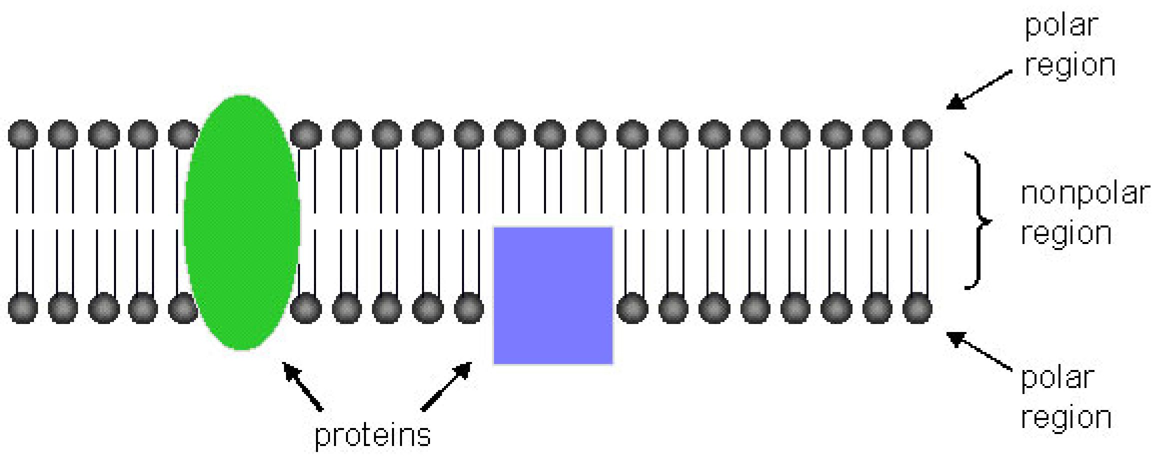
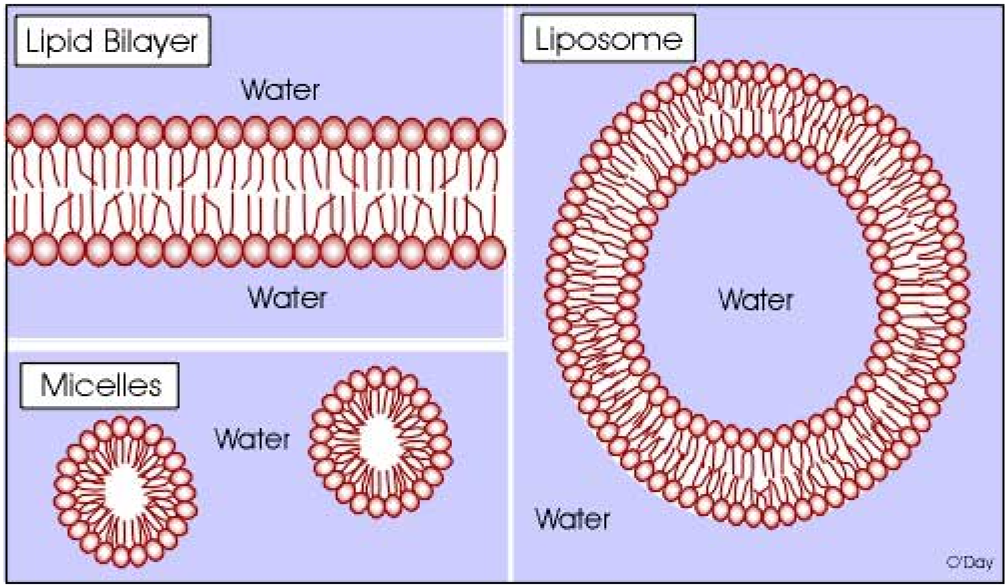
One of the key principles in nanoscience is the ability to create and design particles that are incredibly small, which can be used for a specific purpose. These particles are referred to as nanoparticles. One such nanoparticle is called a micelle. A micelle is a particle that is created by self-assembly. Self-assembly of a micelle occurs by a very similar mechanism to the biological process of formation of the fluid mosaic bilayer that makes up the plasma membrane in eukaryotic cells. The plasma membrane (diagram below) is made up of phospholipids: phospholipids are molecules that contain a phosphate group, which is hydrophilic (water-loving), and a fatty acid-lipid group, which is hydrophobic (water-fearing). When placed in water the fatty acid groups tend to assemble away from the water interface, while the phosphate group gravitates toward the water interface. A stable structure that results from these tendencies is a bilayer or—as I refer to it in my classroom, a "fat" sandwich—in which the phosphates represent the bread of the sandwich and the fatty acids represent the fatty filling. The micelle is formed in much the same way: the phosphate groups arrange so that they are in contact with the water interface and the lipids are facing away from the water interface. The shape of these structures can be altered to suit a specific purpose by varying the types or lengths of the fatty acid chains and whether or not they are generated in aqueous solution or not. (Refer to the appendix for diagramed examples). Once these micelles have been created, they can be loaded with drugs, such as cancer fighting drugs or genetic material for gene therapy.

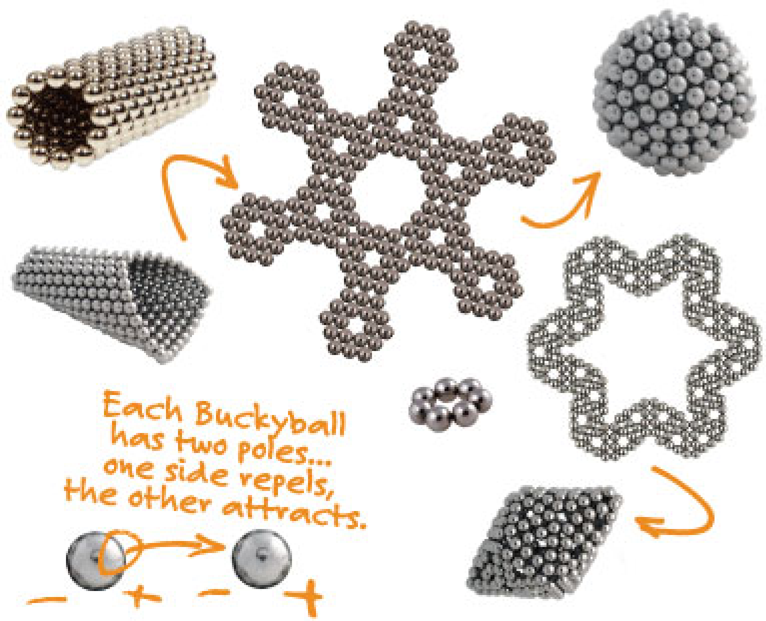
Fluid Mosaic Model of the Plasma Membrane



Another form of nanoparticle is called a buckyball; this is short for buckminsterfullerene (just stick with buckyball). Buckyballs are soccer-shaped structures that are made up of carbon atoms: an atom that makes up most of the structures of living organisms. These particles can also be loaded with drugs, gene therapy vectors, or other biologically active agents. Micelles and buckyballs can be dressed-up or functionalized by adding proteins, enzymes, or antigens to make the particle more likely to bond or be accepted with its designed target. Researchers have developed elaborate configurations in order to accomplish this task. This takes us into another area of science called biomimetics. Biomimetics is the science of mimicking biology or what occurs in nature. When one introduces synthetic particles into a living organism, the immune system reacts to recognize this invasion as foreign and can launch an immune attack against the particle. By encapsulating the micelle or liposome with receptor proteins or antibodies, the nanoparticle has a greater chance of entering the cells of the organism, thus delivering the intended drug or gene sequences. Biometrics is currently being used for such treatments as joint replacement therapy and tissue scaffolding.

Booker in *Nanotechnology for Dummies* shares, "DuPont and Exxon are using buckyballs to develop stronger polymers. These companies are looking at two ways of doing this: by integrating the buckyballs in the polymer with chemical bonding. Or by simply tossing buckyballs into the polymer and embedding them there& …buckyball-based antioxidant type drugs are being developed& hellip;for example, anti-aging or anti-wrinkle creams& hellip;and an HIV Drug." The scopes of these tools are far-reaching and have the potential to become even more so in the not too distant future. A simple search on the Internet will provide numerous articles which offer research being done in this area. Some other forms of nanoparticles include lipid colloids, ceramic nanoparticles (quantum dots), dendrimes, and nanotubles.





Unit Implementation Strategies

The first part of my unit involves introducing the concept of size and measurement. On the first day, I plan to discuss and demonstrate to my students the units of the metric system and then have them develop the skill of measuring accurately. I am going to teach them that the metric system is based on the power of ten and provide concrete examples of items that they can relate to that are for example a meter, a centimeter, and a millimeter. I will then allow them (individually and in groups) to practice their measuring skills in order to gain a comfortable background knowledge. They are going to be presented with several objects: they must first make a prediction of the length and then actually measure the object in SI units. Afterwards, we will discuss as a class the items that they measured and the relationship of their measurement to their prediction. This part of the unit focuses on macroscopic measurements, but the next part of this lesson involves discussion of things they cannot see with the unaided eye, such as those things that must be measured in micrometers and nanometers. The next step is to have the students relate those things they cannot see unaided to their relative size or length. Two good sites for this demonstration are referred to in the appendix. Next we will observe the sites and discuss the relationship of meters to nanometers. To conclude this part of the unit, I am going to have my Honors Biology students read an excerpt from J.B.S. Haldane's essay *On Being the Right Size*. After reading the essay, my students will be asked to write a paragraph discussing how size and scaling would impact the ability of a human to function if he or she was either six centimeters tall or six meters tall (they can choose between on of the two). After they have written and shared their individual responses with the class as a whole, the students will get together as a group and discuss the impact of being six centimeters or six meters on the daily survival of human beings. For example, how would an extremely large or extremely small human eat or drink? Where would he or she sleep? Would he or she be able to function in the world we live in today as we do? They will then list and share what they have discussed with the rest of the class. This section of the unit will probably cover a two block class period.

The second part of my unit will involve using an article by Michael C. LaBarber entitled *The Biology of B-Movie Monsters*. This is a wonderful article which presents B-movie creatures and explains their structure and the physics of their function, which is often different than depicted in the movie. Examples range from the small, *The Incredible Shrinking Man* (1957), to larger creatures, *King Kong* (1933). LaBarber divides his paper into sessions; in the first session, he discusses the relationship between biology and geometry in scaling. He uses this relationship to explore how physiological relationships are affected by a change in size. In session two, LaBarber discusses the effects of scaling down or being smaller on an organism. He gives the example of the shrinking man-"the surface area of his body, through which he loses heat, has decreased by a factor of 70 x70 or about 5,000 times, but the mass of his body, which generates the heat, has decreased by 70 x70 x 70 or 350,000 times. He is clearly going to have a hard time maintaining his body temperature unless his metabolic rate increases drastically."

Session three of LaBarbera's article deals with the other end of the spectrum, creatures that are enlarged in size. He actually refers to Haldane's essay and discusses the strength of bone. "The strength of a bone is approximately proportional to its cross-sectional area; this is simply another way of saying that there is a maximum mechanical stress, or force per unit area, that a bone can withstand." The load the bone must bear is proportional to the mass of the animal& hellip;the load on the bone will increase in proportion to the increase in volume(length cubed), but the cross-sectional area of the bone will only increase as length squared& hellip;the animal's bones would break under its own weight." He goes on to discuss how posture and bone density affects an animals ability to function. LaBarbera has several more sessions, but I am going to focus on the first three, time permitting.

The strategy for this section of my unit is to have the students read each of the three sessions in the article, watch 3-5 minute clips from You-tube of each of the movies, and discuss the concepts presented. The students will then be presented with an assignment in which they will design their own movie monster and justify the feasibility of its survival at its particular size. This activity will be individual projects for my Honors students and a group project for my English as Second Language learners. The students will design their creature and present their project on a poster before the class using, as their guide, a rubric presented to them beforehand. While they are presenting, their classmates will also have the same rubric to critique the presentation. This keeps the entire class engaged through all of the presentations. Upon the completion of this activity, I feel that my students will have a reasonable knowledge of size, measurement, and scaling as it relates to our study of biological system. They will be better able to make these associations as we study organisms from viruses and bacteria to elephants and blue whales. This section of the unit should be covered in 2 block classes.

The final part of my unit will incorporate the science of nanotechnology into the unit I already teach on biotechnology. I will discuss the theory behind nanoscience and present to them some practical applications of how nanotechnology is being used today. In my biotechnology unit, we discuss recombinant DNA using bacteria and plasmids. I will add that plasmids and restriction enzymes are also being used in nanoscience, in creating nanoparticles with biological activity. Our instructor in this seminar, W.Mark Saltzman, presented to us the work that he is doing with nanoparticles and cancer delivery; I want to share this work with my students. Next I want to explain and demonstrate how micelles are formed and the concept of selfassembly. As an activity for this section students in groups will dump Cheerios cereal into a container of water and observe them over a period of time: it is well-known that they will self assemble into hexagonal patterns (this can also be done with Trix cereal or sliced hotdogs). After we inquire, we will make some predictions as a class as to why this phenomenon exists. I am going to present some of the articles which can be found in the appendix from Science Daily which present various products which have been and are being developed in the field of nanotechnology today. There are several articles which present negative views on the use of nanotechnology so my students are going to have to read each and in groups discuss the pros and cons, later sharing with the entire class. This section of the unit should only take one block class period.

All three sections of this unit should take about one week total to complete. In North Carolina, Biology is an End of Course class and we are on a pacing guide; however, I feel that the time spent on this unit will pay off in the long run in that my students will be able to move through this course with increased background information and a better understanding of many of the concepts and applications that will be covered in this unit. This unit will also lay valuable groundwork as these students move through their other courses beyond biology class.

Lesson #1 Measurement and Size Relativity

Materials:

- Refer to Appendix A for student materials.
- Copy of J.B.S. Haldane's essay *On Being the Right Size*

Objectives:

- Students will be able to measure using the SI Metric system
- Students will develop a frame of reference for size from meters to nanometers
- Students will be able to relate the significance of size to the structure and function of living organisms.

Procedures:

I will introduce the metric system and its units of measurement. I want them to recognize that this system is based on the power of 10 and be able to relate objects that are visible (meters, centimeters, and millimeters) to objects that are not visible to the naked eye (micrometers and nanometers). The students will then apply what they have learned by completing the measurement activity. The next part of this lesson will consist of presenting and discussing the two websites, *Cells alive! How Big* and *Size and Scale*; the sites are listed in Appendix A. These sites will give my students a point of reference concerning the relativity of size and various items which we will be covering throughout the course. In the final part of this lesson, I will provide my students with a copy of Haldane's *On Being the Right Size*. I have chosen specific excerpts from this essay as it relates to items we will be covering in this course and am going to divide these excerpts into six sections because I usually have six lab groups in my class. Students could be allowed to view the entire essay individually, but this would be more time consuming depending on the level of student, reading ability, and class size. The students are going to do a modified jig-saw; they will read their assigned sections and then share each section with the class as a whole. The purpose of this exercise is to help the students focus on one aspect of the essay and provide a better discussion in a more reasonable amount of time; each group can share that discussion with the class as a whole. The discussion questions are also provided in Appendix A.

Lesson #2 Biology and Scaling

Materials:

- Copy of Michael LaBarbera's article The Biology of B-Movies
- Student questions for Sessions 1-3 located in Appendix B
- Copy of Build a Monster activity guidelines

Objective:

- Students will be able to relate the principals of scaling and the relativity of size to the structure and function of organisms.
- Students will construct their own creature or monster based on the scientific principals discussed in class and in the B-Movie article

Procedures:

Students will be given a copy of excerpts from LaBarbera's B-Movie Monsters, which will divided into three sessions as it is in the original article. I have constructed a PowerPoint presentation in which I have embedded video clips from Youtube.com of selected movies presented in the article. I did this because many of these movies were made in the 1930's-1980 and my students may be unfamiliar with them. Our school system has just approved our computer system to unfilter the transmission of *Youtube*. We will discuss each session individually after viewing the clips. LaBarbera has included a total of six sessions, the last on size and animal behavior, but due to time constraints, I only plan on discussing the first three. This would be an excellent enrichment activity to visit back to if time permits at the end of the semester.

Upon completion of this activity, the students will be assigned the task of designing their own monsters demonstrating the concepts that they learned from our classroom discussions and the B-Movie article. The students will present their designs to their classmates, who will in turn offer feedback on their creation and the accuracy of their scientific reasoning. The guidelines for this activity and the feedback questions are provided in Appendix B.

Lesson # 3 Introduction to Nanotechnology and its Applications Materials:

- PowerPoint and Student activites found in Appendix C
- Student articles on current topics related to nanoscience or nanotechnology

Objectives:

- xStudents will be able to relate to the scale of nanotechnology and its applications.

Procedures:

For the final lesson in this unit, we will be discussing the nature of nanotechnology and its practical applications. I already have a lesson in which we discuss biotechnology focusing on practical applications such as genetic testing, genetic engineering, cloning, etc. In the PowerPoint that I have generated for this lesson, I am going to add the technology of nanoscience and some of its applications. I have found several articles on the site *Science Daily*. There are articles discussing cosmetics, sunscreen, self-cleaning toilets, as well as advances in medicine. I will discuss what I learned in my seminar on Nanotechnology and Human Medicine: self assembly of micelles, liposomes, and buckeyballs. I will ask my students to research and find current articles demonstrating applications for nanotechnology, many of which are on the market today. The students will share their articles with their lab partners and then select the most interesting to share with the class. We will then discuss the pros and cons of this technology and the potential it has for future use.

Summary

Now, back to the question "Does size matter?"- I hope that by the end of this unit it is evident that in the world on nanoscale, size really does matter. The unique thing about this unit and this topic specifically is that my students will have the opportunity to gain the background knowledge to apply what they have learned across the curriculum. We have discussed principals of geometry, physics, physical science, chemistry, and of course biology. As the students complete these units, they are developing their skills of inquiry as well as gaining a broader understanding of the structure and function of living organisms and the world around them. The students should be able to apply these concepts toward the higher level courses that they will take beyond biology. The most important thing that I want my students to take away from this unit is that even though nanotechnology as a science is relatively new, it already had practical applications in our lives, which will continue to grow in importance with time.

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Appendix A- Materials for Lesson #1

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1. Metric Activity

Metric Measurement Activity

1. Using a piece of string, find the distance around your waist, wrist, and head. Make your measurements in whatever unit appropriate and then convert to the other units.
2. waist = __________m = __________cm = __________mm
3. wrist = __________m = __________cm = __________mm
4. head = __________m = __________cm = __________mm
5. How tall are you in centimeters? __________cm In meters? __________m
6. Obtain a penny, nickel, dime, and quarter. What are the diameter and thickness of each coin, in millimeters? Fill in the chart below, being sure to include units
7. able>

Coin	Diameter	Thikness
Penny		
Nickel		
Dime		
Quarter		

8. Using a meter stick, find out how far you can leap in a standing broad jump.
9. ________m = __________cm = __________mm
10. Estimate the size of the 5 objects, some listed below, in the space provided. Include metric units with your estimates. Then, actually measure the 5 objects and record your results. Don't forget units!
11. able>

Object in Room Estimated Length Measured Length

12. mple items to measure:
13. ameter of a pencil Length of shoeprint Length of index finger
14. ngth/height of the room Length/width of calculator
15. ngth/ width of a textbook Height of desk Diameter of your watch

2. Links for demonstrating size relativity

a. Cells Alive! How Big Interactive http://cellsalive.com/howbightm
b. Cell Size and Scale http://learn.genetics.utah.edu/content/begin/cells/scale/

3. Student Questions after reading J.B.S. Haldane's *On Being the Right Size*

Discussion Questions

Read the assigned section of Haldane's essay and answer the following questions.

Individual Response:

1. Based on your reading of this essay, in one paragraph discuss how size and scaling affects a human's (or any organism, for that matter) ability to function. How would your response change if the individual was 6 centimeters or 6 meters. Give specific examples.

Group Response

After sharing your individual responses, discuss the impact of being six centimeters or six meters on the daily survival of human beings. For example, how would an extremely large or extremely small human eat or drink? Where would he or she sleep? Would he or she be able to function in the world we live in today as we do? Be prepared to share the group's response with the rest of the class.

Appendix B- Materials for Lesson #2 - 1.The Biology of B- Movie Monsters Questions

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SESSION 1: Biology and Geometry Collide

1. What is "scaling"?
2. Answer the following question- What does math have to do with science?
3. What is the relationship between surface area and volume as an object's size increases?
4. How does the concept of surface area-to volume ratio apply to living organisms? Give some specific examples.

5. What are the three physical forces that apply to biology and geometry that are listed in this article?
6. When discussing the properties of water -cohesion, adhesion, and surface tension are listed. Give specific examples of how these properties can be observed in living organisms.
7. Based on gravitational and inertial forces as discussed in the article, why would a bird break its neck if it flies into a window, but the fly would bounce back without injury?
8. Why did the author call movie makers in Hollywood "hopelessly naïve"?
9. List some examples of movies that you have seen in which organisms where larger or smaller than real-life. What characteristics made them more interesting than if they had been shown in there more realistic state?
10. After completing this unit, do you think you will view "monster movies" in the same light? Explain why or why not.

SESSION 2: A World Distorted Beyond Your Imagination

1. What is metabolism? How is the *Incredible Shrinking Man*'s metabolism going to be affected by shrinking by a factor of 70? List at least 4 examples.
2. n the contest between the man and the spider, who would have the advantage? Explain why.
3. What happened to the unsuspecting visitors in *Dr. Cyclops*?
4. Why did these small visitors not have to be concerned about climbing up or down the now massive-sized furniture?
5. What is velocity? What is terminal velocity? How are these forces affected by gravitational forces?
6. What is kinetic energy? Why is being small a good thing in regards to kinetic energy?
7. According to the article, what are two science-based methods of shrinking objects or monsters? Why would neither of these not be a feasible option in reducing size?
8. What other obstacles of being small did you observe in the video clips?
9. List some adaptations you would have to make if you were reduced in size like the Shrinking Man?
10. What is meant by the following statement, "…it's not the fall that hurts you, it's the sudden stop at the end…"

SESSION 3: The Bigger They Are, The Harder They Fall

1. Explain why many large terrestrial animals are now extinct.
2. What are some of the major flaws in the movie monster King Kong?
3. List two factors that affect the strength of bones.
4. How do the does the change in an animal's posture reflect the bone's ability to support the animal?
5. How would King Kong's size affect his metabolism? Was this behavior observed in the video clip?
6. List some specific obstacles you would have to face if you were 50 percent larger.
7. List some movies that you have seen in which the characters were "larger than life". What interested you about these characters?
8. In session three the author states, "The bigger they are, the harder they fall". Explain how this statement relates to the biology of structure fitting function in living organisms.
9. Consider the Giant Sequoias trees- how are these plants adapted to grow and function at such massive sizes?
10. How do aquatic animals such as Blue Whales physically adapt in their own unique habitats?

2. Build a Monster Activity

Build a Monster

Now that you observed the monsters in B-movies, it is now time to see what you have learned and demonstrate your creativity.

Your mission-and you have no choice but to accept it- is to build your own miniature or gigantic monster of your own.

You will use the following guidelines:

1. Choose whether or not your creature is going to be 6cm tall or 60 meters tall.
2. Describe the daily activities of your creature and the obstacles it would face if it lived in "our world"
3. Design a poster which illustrates the creature and how it will adapt to its new habitat.
4. Be able to defend to your classmates how and why you designed your creature using at least 3 of the scientific principals we have discussed in the article The Biology of B-Movies.
5. Present your poster to your classmates.

Build a Monster Peer Review

Student Presenting ______________________

Type of Monster/Name ______________________

1. How realistic was this creature? Explain your answer.
2. Was this creature designed to follow the basic principals of science which we have studied in B-Movie Monsters? Give specific examples.
3. Explain what interested you about this creature.
4. What questions do you still have concerning the construction of this creature?
5. How would you have designed this particular creature differently?

Appendix C- Nanotechnology and its Applications Resources

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1. Site for PowerPoints on Nanotechnology and Student Activitie

"Introductory Level Modules - NACK Educational Resources." Access NACK Resources - NACK Educational Resources. http://nano4me.live.subhub.com/categories/modules (accessed July 27, 2010).

- Example of site for current event articles
- http://www.sciencedaily.com/videos/2006/0611-nantechnology_whats_that.htm

Appendix D- Suggested media relating to size, if time permits in your lesson planning:

- *Alice in Wonderland* (original as well as recently released version)
- *Gulliver*'s *Travels*
- Meet Dave
- Honey I Shrunk the Kids
- Osmosis Jones
- Jurassic Park
- The Incredible Hulk
- Jack and the Beanstalk
- Horton Hears a Who
