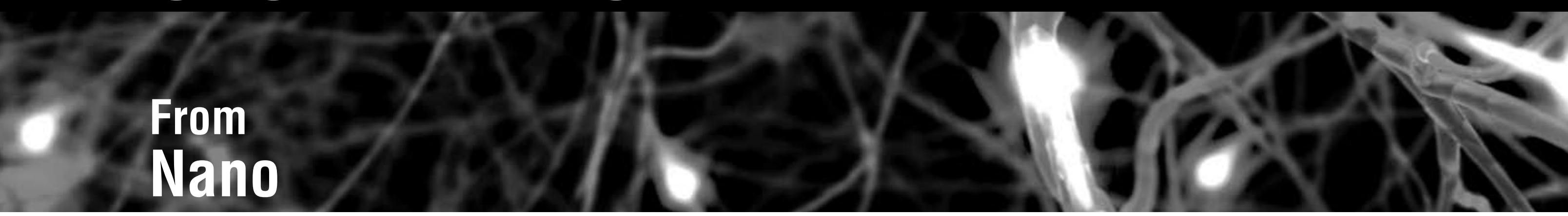
EXTREME SCIENCE



From
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EXTREME SCIENCE

From Nano to Galactic

Investigations for Grades 6–12

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NSTA press
National Science Teachers Association

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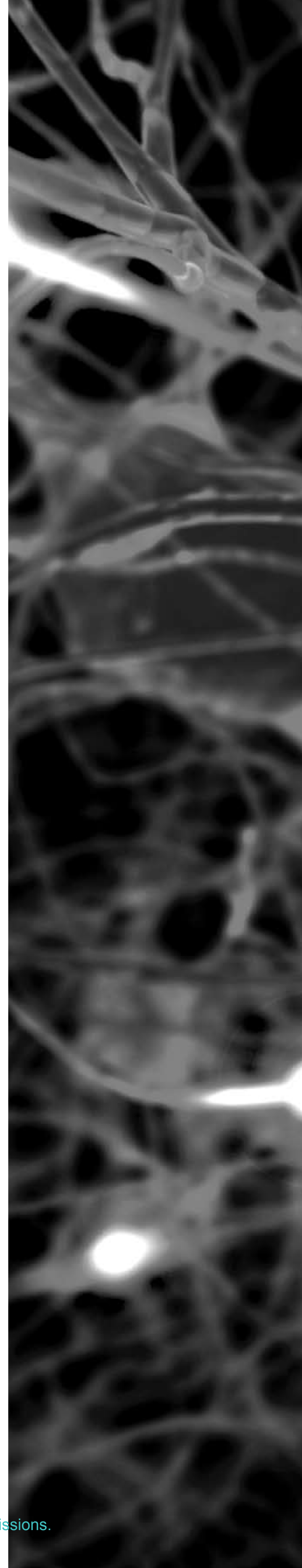

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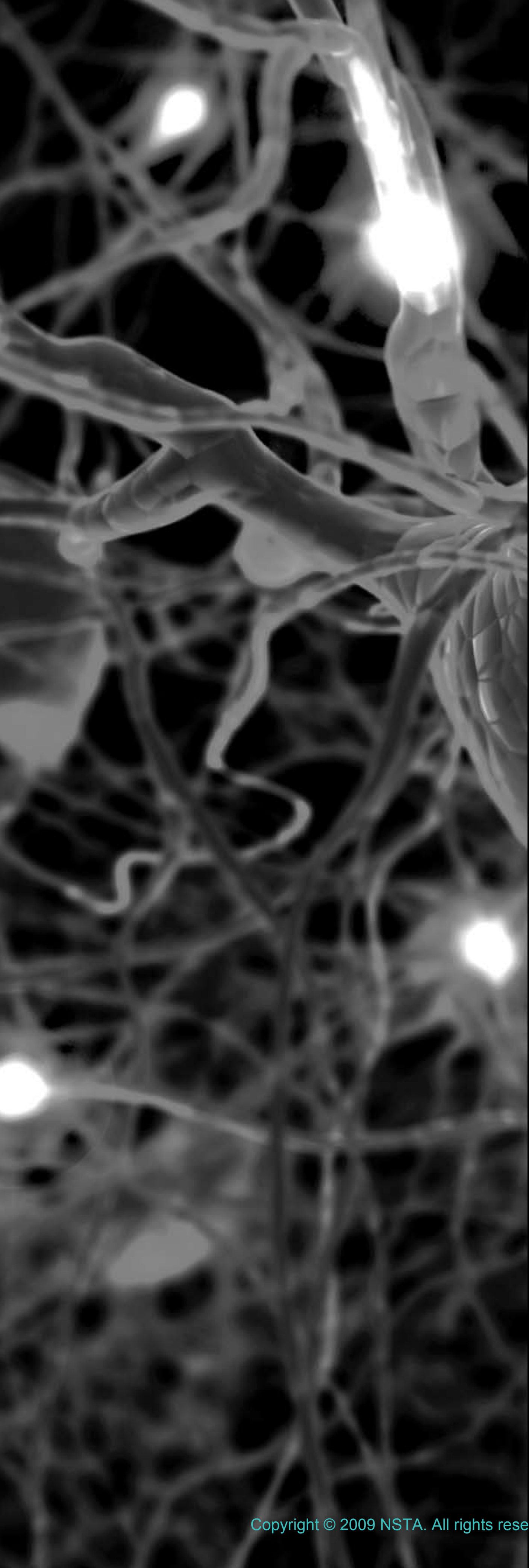

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Finally, we want to express a most sincere thanks to the many students (from elementary through graduate school) and teachers who have participated in a long series of studies focusing on learning scale and scaling. These individuals have enriched this book in many ways.

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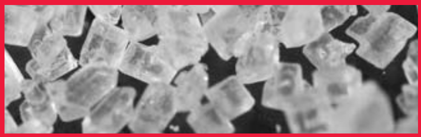

SURFACE AREA-TO-VOLUME RELATIONSHIP

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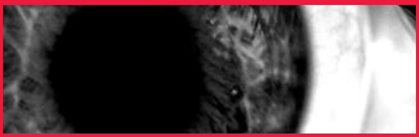

BEHAVIORS & SCALE

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Dedication

This book is dedicated to Carolyn, Herb, Nancy, Tina, Sonia, and Toby, who have supported and inspired us in our work in science and education.

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INTRODUCTION

EXTREME SCIENCE

From Nano to Galactic

Whether we are imagining microbes or mammoths, dinosaurs or diatoms, molecules or stars, people of all ages are fascinated with the very large and the very small. Our interest is piqued as we try to imagine the world from a very different perspective—for example, looking up at the world through the eyes of an ant or looking down from the height of a dinosaur. New technologies have enabled scientists to investigate extremes of science previously unknown. Since the development of the telescope nearly 400 years ago we can explore vast worlds beyond our human perception. At the small scale, new advances in microscopy now enable us to manipulate and experiment with individual atoms and molecules. Some of the most striking new developments in science occur at the extreme ranges of scale—the very large (galactic) and the very small (nanoscale). In presenting these new and exciting scientific topics, the teacher faces the additional challenge of introducing the daunting concepts of scale over vast ranges.

Why Scale and Scaling?

An understanding of scale and scaling effects is of central importance to a scientific understanding of the world. Advances in diverse areas such as astrophysics, chemistry, biotechnology, nanoscience, geography, and sociology depend on being able to conceptualize different scales, as well as the effects and laws of nature that apply to each system scale. Most scientific problems cannot be approached without first appreciating the scale of the situation to be investigated. Though scale has always been central in science, an argument can be made that within the currents of scientific thought, it has never been more important than it is right now. A new appreciation of complexity or complex systems has taken hold in all areas of science, from supercon-

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ductivity to schooling phenomena in fish, from weather modeling to research on human consciousness (Gallagher and Appenzeller 1999). In 1972, Nobel laureate physicist P. W. Anderson wrote an editorial in *Science* titled "More Is Different" in which he described the concept of "emergent phenomena" (Anderson 1972). As the title suggests, Anderson articulated the idea that completely new rules emerge as the scale of a system changes. In the decades since, this simple yet new idea has influenced all areas of science. This new focus in scientific thinking is driven by advances in scientific technologies such as advanced microscopy and supercomputing, among many others, which have allowed us to access new regimes of scale, to amass huge amounts of data, and to map out systems at a level of detail unimaginable even 20 or 30 years ago. It has also, as Anderson prophetically pointed out in his essay, encouraged an ever-strengthening movement toward cross disciplinarity in science. In this sense, the theme of scaling effects and complex phenomena has acted to bridge disciplines in the world of scientific research in much the same way as the American Association for the Advancement of Science (AAAS) recommends for K–12 science education.

Scaling conceptions are one of four recommended unifying themes in the AAAS Project 2061 Benchmarks for Science Literacy (1993). Understandings of unifying themes such as scaling may serve as a solid framework for students to anchor further learning in a variety of disciplines and allow them to make cross-curricular connections among seemingly disparate topics. Table 1 shows the big ideas about scale that are recommended across the curriculum.

The U.S. science and mathematics curricula have been criticized as lacking coherence (AAAS 1989; National Council of Teachers of Mathematics [NCTM] 2000; National Research Council [NRC] 1996; National Science Teachers Association [NSTA] 1993). The claim that "the present curricula in science and mathematics are overstuffed and undernourished" (AAAS 1989, p. 14) effectively captures a view of the present state of most science curricula in the United States. This lack of coherence is not only a weak point in many science curricula, but also a stumbling block to effective science learning: "The typical U.S. science program discourages real learning not only in its overemphasis on facts, but in its very structure, which inhibits students from making important connections between facts" (NSTA 1993, p. 2).

That lack of coherence may contribute to the underdevelopment of a scientifically literate citizenry able to understand how scientific ways of thinking contribute to our society. An international comparison conducted during the Third International Mathematics and Science Study (TIMSS) reported that the splintering and fractionalization of U.S. science and mathematics curricula are also evident in comparison with those of other countries around the globe (Schmidt, McKnight, and Raizen 1997).

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Numerous reform groups have recommended the use of big, overarching, unifying themes to combat the lack of curricular coherence and help students weave a fabric of understanding from the many components of a science and mathematics education (AAAS 1989; NCTM 2000; NRC 1996; NSTA 1993). Rather than representing specific content knowledge within specific disciplines, these themes represent scientifically useful ways of thinking about our world and society. Such unifying themes not only cross traditional disciplinary boundaries, but also develop over the entire course of a K–12 education. Thus these themes need to be well articulated across age groups, as well as across specific disciplinary content, to facilitate the growth of students' knowledge as a rich fabric of understanding rather than isolated bits and pieces of knowledge. For example, an understanding of scale can bridge gaps and provide a framework for concepts in mathematics (e.g., number sense, fractions), geography (e.g., landmass, populations), or Earth science (energy use).

TABLE 1.
Benchmarks for Science Literacy: Concepts of Scale

What students should know by the end of

Grade 2: Things have very different sizes, weights, ages, and speeds.

Grade 5: Things have limits on how big or small they can be.

Grade 5: The biggest and smallest values are as revealing as the usual value.

Grade 8: Properties depend on volume change out of proportion to properties that depend on area.

Grade 8: As the complexity of a system increases, summaries and typical examples are increasingly important.

Grade 12: Representing large and small numbers in powers of ten makes it easier to think about and compare things.

Grade 12: Large changes in scale change the way that things work.

Grade 12: As the parts of a system increase in number, the number of interactions increases much more rapidly.

Summarized from *Benchmarks for Science Literacy* (AAAS 1993, pp. 277–279).

Emerging Nanoscale Developments

A look at just one aspect of scale—nanoscale—shows a need to educate the public about the rapid developments in nanotechnology. The National Science Foundation (NSF), along with 17 other agencies and departments in the National Nanotechnology Initiative, has identified a need to educate students and citizens about advances in the nanoscale sciences. Innovations and changes in nanotechnology are happening very rapidly, and some scientists speculate that nanotechnology will replace genomics as the next scientific revolution. The NSF has committed more than $100 million for nanotechnology research centers, undergraduate education programs, and nanoscale science and edu-

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cation. From the federal level, there is a tremendous demand for students who can fill jobs in nanoscale science and an even greater demand for an educated citizenry that can participate in the decisions that will arise from advances in nanotechnology. Already students can buy clothes in stores that are covered with "nanocare" stain-resistant technology, nanocarbon balls are being sold to keep refrigerators odor free, and nanoscale channels sample glucose levels in small diabetic monitors. Citizens may soon be asked to make decisions about injectable, nanometer-sized blood monitors that will float in the bloodstream, or the potential release of nano-sized pollution scrubbers into the atmosphere, or whether we should use nanotechnology to rearrange atoms in designing molecules. If people don't know how small a nanometer is (10^{-9} meters) and cannot conceptualize the scale of materials of this size, how can they begin to make decisions about the efficacy and ethics of the emerging technologies?

Scaling effects are often complex, and teaching scaling effects is a particular challenge for educators. For example, at the smallest of scales, counterintuitive properties emerge. Along with extensive properties such as mass, volume, and surface area, properties normally thought of as intensive, such as color, conductivity, magnetization, and hardness, change as an object becomes small and approaches the nanometer scale. The color of semiconductor quantum dots can be changed continuously by altering nothing but the size of the particle (Bruchez et al. 1998). If made small enough, a magnetic iron particle will completely lose its magnetism (Majetich and Jin 1999). Individual silicon nanospheres between 40 and 100 nanometers in size exhibit much greater hardness than bulk silicon (Gerberich et al. 2003). At this scale, nature has different rules, some of which are beautiful and unexpected.

At the nanoscale, properties of objects are dramatically different from those at the macroscale. These properties include ***bumpiness:*** Things tend to be *bumpy* rather than *smooth*. "Bumpiness" not only refers to geometrical bumpiness but also includes bumpiness in the magnetic, electronic, optical, and mechanical properties. ***Stickiness*** takes over at the nanoscale, and everything sticks together; gravity is irrelevant. At this scale relevant forces include the van der Waals forces, hydrogen bonding, and hydrophobic bonding. For very tiny objects at the nanoscale, ***shakiness*** dominates; everything shivers and shakes, and nothing stands still.

Size and Scale

The influence of scaling effects on size acts as a limiting factor for many flora and fauna (Stevens 1976; Brown and West 2000). The recent discovery of the dime-sized world's smallest lizard highlights an example of scaling effects determining a physiological lower size limit for such an animal. As the biologist who discovered it remarked, "If we don't provide a moist environment when

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we collect them, they rapidly shrivel right up and die by evaporation from the proportionally large area of their surface" (NSF 2002, p. 14). At an intersection of biology, chemistry, and physics, gecko setae—the millions of tiny hairs that branch off the toes of a gecko—provide enough adhesive force for geckos to climb virtually anything using van der Waals forces. These forces become significant only at very small scales, and that is why the small size of the setae is vital for the gecko's climbing ability. Scientists have nanofabricated artificial setal tips from different materials and observed the strong adhesive properties that are due to their size and shape, potentially leading to the manufacture of the first dry adhesive microstructures (Autumn et al. 2002). As Thompson writes about scaling effects in his classic work *On Magnitude*, "The predominant factors are no longer those of our [human] scale; we have come to the edge of a world of which we have no experience, and where all our preconceptions must be recast" (Thompson 1917/1961, p.48).

Limits to Size

Humans have long been curious about creatures of minuscule or gargantuan extremes of size, as is evident in the themes of many movies and books. Could a person shrink to the size of an ant and survive? Could a butterfly grow to the size of an airplane? Why or why not? Answers to these questions and many others that students ponder can be illuminated through investigating limits to size. Limits to the size of physical structures, especially that of living organisms, are influenced by factors such as surface tension, gravity, allometry (differing growth rates), diffusion, support structures (i.e., bones), and surface area-to-volume ratios. These limits to size can be applied at the cellular level or to the whole organism. The same factors that limit the size of a cell also limit the size of the organism. Body temperature regulation, metabolism, uptake of nutrients, disposal of waste products, cell growth, enzymatic activity, and bone structure/length are all scale dependent.

An animal's mass and the stress on its bones must also be considered. Structural support for our bodies (bones) cannot be scaled up to the size of a skyscraper and still function properly. For example, imagine holding down one end of a meterstick on the edge of a table. The stick will remain almost straight, bending only very slightly by its own weight, even if cantilevered out most of its length. If we simply scale a meter stick up 200 times, so that it is 200 m long and perhaps 1.0 m thick, this scaled-up version will break under its own weight if most of its length is cantilevered and unsupported. Simply put, the larger the mechanical supports, the more they distort under their own weight, even if scaled proportionally. So an organism's bones, if scaled to large enough size, would simply break under their own weight. Even though larger land animals have thicker leg and arm bones in proportion to their body size,

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there is a certain body size above which bones become too weak to support the body.

Limits to size and surface area-to-volume ratios obviously play a role in processes occurring in living things. These relationships play a role in physical and chemical reactions that occur as well. The dominant forces and types of bonding may shift as one's investigations move from the macroscale to the nanoscale. Rates of chemical reactions also change depending on surface area-to-volume relationships.

The Habit of Quantitative Thinking: Scale and Understanding Our World

Dealing comfortably with large and small numbers and appreciating the absolute and relative scales of those numbers are essential skills not only in the sciences but in any endeavor where quantitative evaluation is important. A goal of this book is to help students develop those skills through quantitative exploration of groups of numbers that are particularly interesting (the fastest animals, the tallest buildings) and particularly important (the populations of the largest cities, the population of the entire earth, the age of the Earth). Exploring these concepts not only provides an interesting context in which to practice quantitative manipulations and comparisons, but also provides content knowledge for students in subjects of scientific, social, political, and economic importance. In the context of populations, developing a quantitative conceptualization of the absolute scale of national and world populations will undoubtedly come in handy as the students start wrestling with social and political issues including globalization, economics, and environmentalism. Developing an understanding of absolute time scales and benchmarks (from human and historical time scales to geological and evolutionary time scales) will inform and greatly enhance students' understanding of subjects as varied as history, geology, and evolution.

It is also crucial for students to gain an understanding of the appropriate degree of precision for discussing quantitative information and to recognize the power and utility of estimation. For example, there are between 6 billion and 7 billion people currently living on Earth. Knowing that there are 6.62 billion is of little additional utility in most contexts and can in fact imply greater precision than is appropriate (by they time you read this it might be 6.63 billion). Exercises providing students practice in the art of rough estimation, or "order of magnitude" estimates of quantities in question, will help them gain comfort with the habit of quantitative thinking while simultaneously familiarizing them with the size of important numbers that describe their world. The numbers that describe our world cover a mind-boggling spectrum of magni-

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tudes; identifying the correct scale is the essential first step. A student with the skill to make an educated guess at the magnitude or scale of a problem can reach into her toolbox and pick the proper ruler.

Overview of Investigations

This book is organized into a developmental framework that includes the following sections: an introduction to types of scale, measurement, powers of ten, estimation and models of scale, surface area-to-volume relationships, limits to size, and behaviors at different scales. These sections are designed to help students develop skills in measuring and applying scale, an appreciation for the value of different scales in scientific work, and an understanding of the powerful role that scale has in limiting natural systems, as well as to lay a foundation for students to investigate more complex issues in scaling, such as how phenomena and materials behave differently at different scales.

The instruction is designed so that it can be used flexibly at the middle and high school levels. Each investigation is designed around a modified learning cycle (engage, explore, explain, extend, and evaluate) that begins with background information for the teacher and lists of specific objectives and process skills. The "Engage" section presents a question, challenge, or phenomenon for students to consider. It is followed by the "Explore" section, in which students actively investigate an area of scale. Students then attempt to make sense of their investigation, in collaboration with their peers and the teacher, in the "Explain" section. The "Extend" part of the lesson guides students into thinking of new or different applications or uses for scale. Finally the students are presented with a series of questions that evaluate their understandings of the investigation. The lessons are designed to build scale concepts across the different science domains (see Table 2, p. xxiii).

Introduction to Scale

The book begins with an investigation, *What Is Scale?* in which the range of extreme scales is explored by a fact-or-fiction activity. In the activity *Types of Scale*, students examine the array of different scales that exist for measuring time, mass, volume, and length, as well as less-well-known scales that are used for rating and measuring things such as clouds, wind, earthquakes, or the hardness of rocks.

Measurement

Measurement skills are taught in various investigations. However, in the activity *Oops! I Did It Again: Errors in Measurement*, students measure using different metric and English units, explore the history of measurement, and examine errors in measurement by looking at repeated measurements and random errors.

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Powers of Ten

Students' examination of the powers of ten begins with the card-sorting activity, *Sort It Out*, in which the students think about objects from the very large to the very small and sort them according to size. This investigation challenges them to think about both horizontal and vertical scale. For example, they must decide which is larger—the height of the Empire State Building or the diameter of the Earth. The next challenge is to compare relative and absolute sizes of things in the investigation *It's Not All Relative: Relative Versus Absolute*. This task involves students in placing objects on a string number line, first with relative size and then by adding the appropriate power of ten to each object. Students have to think about the meaning of 10^0 and how to order a series of objects that range in size from 10^{-5} meters to 10^5 meters. *Scaling the Solar System* involves students in scaling the solar system down to the size of a large field and determining the relative size and location of each planet. In the activity *Time Flies*, students explore the geological time scale in the context of major events from the biological, physical, and Earth sciences, as well as from their own personal lives. What are the largest cities on Earth? How do the sizes of other cities compare with the size of your hometown? By pursuing these questions in depth in the activity *Billions of Us*, students also gain knowledge of the absolute scale of important numbers that will help them better interpret their world.

Estimation and Modeling

Skills in estimation and modeling are extended in a series of investigations. Through the lesson *Scale It!* students learn how to create models at different scales, as well as map the school environment at different scales. *Mega Virus* takes students from the nano world (10^{-9} meters) to the macroworld (10^0 meters) as they build a giant icosahedral virus model.

Your World or Mine? Different Perspectives involves students in examining objects and environments from different perspectives. Students draw the environment looking down from a bird's nest high in a tree and looking up at a potted plant from the perspective of an ant. They draw the phases of the Moon as viewed from Earth. Large scale is examined in the investigations using GIS (Geographic Information Systems). In the lesson *Eye in the Sky* students use satellite data to look at the environment. With a zooming tool they are able to map the increasing detail that is revealed about their environment such as tree canopies, Africanized honeybees, and topography. In *Drops to the Ocean* students investigate river basins and map scale using GIS as a tool. They work first with paper maps, establishing relationships between terrain and water flow. Next they investigate how map scale determines the level of detail shown on paper and interactive GIS maps. Magnification is explored in *Zoom Zoom: Magnification* with hand lenses, video cameras, and microscopes, as students examine and draw different objects at varying magnifications.

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Surface Area-to-Volume Relationships

Limits to the size of organisms and their structures go hand and hand with surface area-to-volume ratios. Because this relationship affects so many aspects not only of living organisms but also of physical and chemical processes, students investigate various scenarios in which surface area-to-volume relationships are evident. By completing the activity *That's Hot!*, students begin to understand that surface area size affects the rates of evaporation, heat loss, diffusion, and water loss. In the investigation *SWEET! Exploring Surface Area of Sugar Molecules* the phenomenon of gravity is examined in relation to surface area-to-volume ratios of various structures.

Limits to Size

Students learn how scale limits a number of processes and phenomena in the natural world through investigating the pore size of eggs or the exoskeletons of insects and other structures found in living organisms. Processes that occur in living things are only efficient under certain conditions. For example in the activity *Captivating Cubes* students model the efficiency of diffusion into and out of a cell, as determined by the cell's surface area-to-volume ratio. This principle is explored by students in activities such as *Eggsactly* (investigating diffusion of gases to the chick embryo in eggs of various sizes) and *Attack of the Giant Bug?* (investigating how the size of an insect is limited by processes of respiration, as well as the weight of the exoskeleton).

Behaviors and Scale

One of the more challenging ideas that students need to become acquainted with is that materials may behave differently at different scales. For example, gravity and magnetism, although present, may play minor roles on the behavior of materials at the nanoscale, where electrostatics or friction has significant influence on materials. Students explore the movement of materials such as Styrofoam of various sizes in *Flying Foam: The Scale of Forces*. The influence of static on balls of different sizes is investigated in *Stick With It,* which models the changes in behavior that take place at very small scales.

Students investigate self-similarity of geometrical features at different scales for fractal objects in *Fractals: Self-Similar at Different Scales*. This investigation involves students in examining fern fronds, tree symmetry, and river patterns, as well as creating fractals from basic patterns. This lesson sets the groundwork for more complex systems levels of scaling that are often used in science. Light is just one type of electromagnetic radiation and belongs to what scientists call the *visible* portion of the electromagnetic (EM) spectrum. In the activity *Screening My Calls: Scale and the Electromagnetic Spectrum* students explore the properties that vary dramatically as the scale of the wavelength changes. Using the electro-

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magnetic spectrum as an example, students consider how different scales give rise to very different phenomena. *Stringy Chemistry and States of Matter* explores the important concept that molecules come in many different sizes. The size of molecules is one of the most important of the parameters that determine the properties of a substance. Scaling is applied in *Our Amazing Senses*, in which students examine the magnitude of difference in our perceptions of soft and loud sounds. They explore how few particles our senses of smell and sight can detect. The investigation *Beetlemice Multitudes!!! Power Law and Exponential Scaling* uses an imaginary population to explore exponential growth. Students determine the population growth over time and the amount of space that would be needed to contain it. Students are then challenged to apply power law to figure out whether a set of cubes and spheres are hollow or solid.

A Sense of Scale

One of the goals of science education is to help students develop a meaningful *sense of scale.* Students should be able to measure, estimate, and apply scale in different contexts. To have a meaningful sense of scale means that students are able to predict and monitor their investigations to know when their quantitative measurements are significantly in error.

One way we gain an intellectual understanding of our world is through numbers. Quantitative scales are where the world and numbers meet; they serve as the standards for measuring that world. A scale is ultimately a magnitude (a pure number) and a unit (a chunk of the world) tied together in a useful way. To measure, or quantitatively understand, something requires the ability to identify the appropriate unit (what kind of thing is it? what ruler should I use to measure it?) and the appropriate magnitude (how big is it?). Professionals ranging from physicists, to earth scientists, to social scientists, to politicians who use numbers as a part of their daily work gain skill in identifying these appropriate units and magnitudes. Comfort with the ability to estimate and evaluate quantitatively is crucial in a wide range of intellectual efforts, and it comes down to identifying the appropriate scale: What unit? What magnitude?

Research on learning is beginning to document the skills and concepts that students need to master as they develop a sense of scale (see Figure 1). Learning scale begins with learning about quantities and numbers. For young children this translates into learning about sizes and amounts. From early in school, measurement skills are critical if students are to be able to understand size and scale. Learning what measurement tool to use and how to use tools accurately continues throughout schooling. Our research has found that scientists report childhood experiences building and making models as very important in their development of a sense of scale. Scientists also report that frequent

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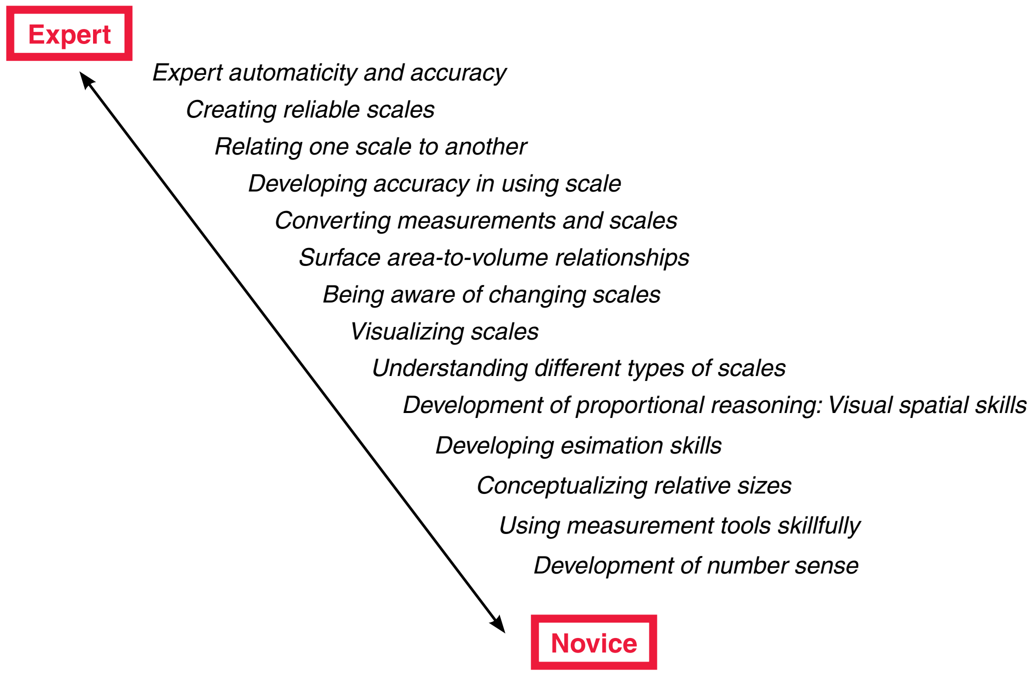
FIGURE 1.
Skills and Concepts to Develop a Sense of Scale.



opportunities to explore the outdoor world through hiking, biking, and traveling in cars and planes helped them understand scale and how perspectives of size change with distance (like watching a ship come across the horizon). In middle school, students' increased proportional reasoning and visual spatial skills enable them to conceptualize more complicated aspects of scale, such as surface area-to-volume relationships. This includes being able to visualize mentally and to manipulate scales and changes in scales. At the more expert levels of scale use, scientists learn to invent reliable scales (not unlike operationally defining variables in experiments) as well as to use measurements with rapid automaticity. Experts in science report that they use "body benchmarks" as conceptual rulers to make estimations quickly, measuring with their fingers or arms or pacing off distances. Other critical strategies included developing conceptual anchors (such as the size of a carbon nanotube or the size of a cell) that helped scientists navigate from the human-sized world to smaller worlds at the micro- or nanoscale. These skills of inventing scales, developing benchmarks, learning to estimate, and applying body rulers can be taught throughout schooling and can help students learn and apply scale in different science contexts.

The investigations in this book are designed to help students develop a comprehensive and flexible sense of scale through experiences with the quan-

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titative units and tools of science. The investigations build on our research, which has documented how people learn scale. The goal of the book is for all students to develop a meaningful *sense of scale*. Understanding scale is where a quantitative understanding of the world begins.

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TABLE 2.
Investigations and Science Domains

Investigations	Biology	Physics	Chemistry	Mathematics	Earth Science
Introduction to Scale					
What Is Scale?	•	•	•	•	•
Types of Scale	•	•	•	•	•
Measurement					
Oops, I Did It Again: Errors in Measurement	•	•	•	•	•
Powers of Ten					
Sort It Out				•	
It's Not All Relative: Relative Versus Absolute					
Scaling the Solar System				•	•
Time Flies When You're Learning About Scale!	•				•
Billions of Us: Scale & Population				•	•
Estimation & Models					
Scale it!				•	
Mega Virus	•			•	
Your World or Mine? Different Perspectives				•	
Eye in the Sky: An Introduction to GIS & Scale					•
Drops to the Ocean: A GIS Study of River Basins					•
Zoom Zoom: Magnification	•	•		•	•
Surface Area-to-Volume Relationships					
That's Hot! The Effect of Size on Rate of Heat Loss	•	•	•		•
SWEET! Exploring Surface Area of Sugar Molecules		•	•	•	
Limits to Size					
Captivating Cubes: Investigating Surface Area-to-Volume Ratio	•	•		•	
Eggsactly	•			•	
Attack of the Giant Bug?	•			•	
Behaviors & Scale					
Flying Foam: The Scale of Forces		•		•	
Stick With It		•		•	
Fractals: Self-Similar at Different Scales	•	•		•	
Screening My Calls: Scale & the Electromagnetic Spectrum		•		•	
Stringy Chemistry & States of Matter		•	•	•	
Our Amazing Senses	•	•	•	•	
Beetlemice Multitudes!!! Power Law & Exponential Scaling	•	•		•	

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Chapter 8

Billions of Us: Scale & Population

Overview

Population is increasingly important as both a scientific and a political subject. The world is getting more crowded. Providing students with the tools to understand population numbers is not only important for their basic understanding of their world, but it is also essential for their future navigation of social and political subjects ranging from energy use and the environment to globalization and the economy. How many people live in your city? Your state? Your country? Your world? How many people live in the United States versus China? This exercise helps students explore the magnitudes of populations and build familiarity with the scales of city, country, and world populations. A related exercise explores the connection between population and energy consumption by comparing the populations of various countries and their corresponding use of oil.

Objectives

- To use examples of different magnitudes to explore the sizes of things.
- To compare and contrast populations of the world, students' own city, and the world's largest cities and countries.

Process Skills

- Applying data
- Comparing and contrasting
- Manipulating ratios
- Modeling

Activity Duration

60 minutes per section

Background

Big numbers, small numbers, and scaling concepts are often presented to students in the abstract. Students typically learn to manipulate numbers mathematically and understand the powers of ten independently from concrete examples in their world.

However it is also important that students attach these mathematical tools—namely scale concepts and powers of ten—to familiar, real-world examples. Of particular interest to children are comparisons between the largest and smallest things (buildings, mountains, dinosaurs) and the fastest and slowest (animals, planes, spacecraft). Exploring a range of examples not only provides exercise for the understanding of large numbers and scale but also provides important content knowledge. Gaining a rough but accurate working knowledge of numbers such as the populations of the United States and the Earth, the age of the United States, and other historical and geological/evolutionary scales is valuable in developing mathematical skill. These exercises also provide students with the outlines of quantitative content knowledge that is crucial to their navigation of the scientific, social, and even political concepts that they will face in their education and adulthood.

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Population: Knowing the Magnitude

One of the most important skills that scientists and technical professionals learn is how to mentally catalog magnitudes of important numbers. This does not mean that they memorize numbers but that they have a working understanding of the rough size of the numbers. In its purest form, this means knowing a number to the nearest significant digit. For example we all know the rough magnitude of the height and weight of the average human adult: roughly five feet and somewhere between 100 and 200 pounds. This is a very rough range, but we know that 10 feet and 1,000 pounds is wrong. Most of us have a hard time giving even this close an estimate of the population of our own city, state, country, or world. The exercise in this chapter help students gain an understanding of the scale of these different population categories. Emphasize that when making these important estimates, getting the answer exactly right is not the point. In fact it can distract us from the more important point: the magnitude of the number. We want to know roughly how large these numbers are (e.g., "around 10 million," not "13.3 million"; "around 500,000," not "517,000"). The extra precision is of little use in gaining an understanding of the scale of the number in question.

Materials

For each student:

- Student Data Sheets
- Drawing materials (pencil or pen, paper, ruler)
- Construction paper
- Scissors
- Small stackable objects of uniform size (pennies, Lego pieces, popsicle sticks)

Note: Each student or group should have access to several dozen of these pieces.

Preparation: If you do not have access to the internet for students to look up population statistics, have a few numbers on hand prior to this exercise: the population of the city (or cities) the students live in and the population of another well-known city in your state (perhaps the biggest city or another large city).

Engage

Distribute the Student Data Sheets and instruct the students to study the table in Part A, City Scales. The first exercise requires the students to enter the population of their city and another important city in their state. This can be done either by providing the statistics or by having the students research them on the internet, in class, or at home the night before the exercise. In Part B,

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Paper Cities, the students are then required to cut out pieces of paper whose areas represent the populations of several of the world's largest cities. In the simplest case, the students can draw squares on sheets of paper to represent the populations, if scissor use is not convenient. The main goal for the students is to derive a scale by which to determine the appropriate size of each paper city. As suggested on the Student Data Sheet, it is prudent to start with the biggest city when determining an appropriate scaling. You want your biggest city to use up most of whatever sheets of paper you will be using. If you are using standard 8.5 × 11-inch sheets of paper, you will be able to make squares of roughly 20 × 20 cm.

- Starting with a standard 8.5 × 11-inch piece of notebook paper, cut out a 20 cm × 20 cm square, which will represent the population of the largest world city (Mumbai).

- This 20 cm × 20 cm square has an area of 400 cm^2.

- The largest city is Mumbai with a population of 13,000,000 people.

- So our scaling is 13,000,000 corresponds to 400 cm^2.
  - 13,000,000 people : 400 cm^2
  - So 1 cm^2 corresponds to 32,500 people; our scaling is (1 cm^2 / 32,500 people)
  - Paper city area in cm2 = population × (1 cm^2 / 32,500 people)

- Example: New York City, population 8,140,000.
  - Paper city area = (New York population)(scaling) = 8,140,000 (1 cm^2 / 32,500 people)
    = 250 cm^2

- If we are making a square city, the square root of this area will give us the length of the side of the paper city.
  - Length of side of paper city = $(250\ cm^2)^{1/2}$
    = 15.8 cm

- After entering the information in the table in Part B, measure out a square 15.8 cm × 15.8 cm and cut it out. This square paper city will represent the population of New York City.

An example of the sizes of selected paper city areas, based on this scaling, is shown in Figure 1 on page 112. The small, unlabeled square represents Raleigh, North Carolina.

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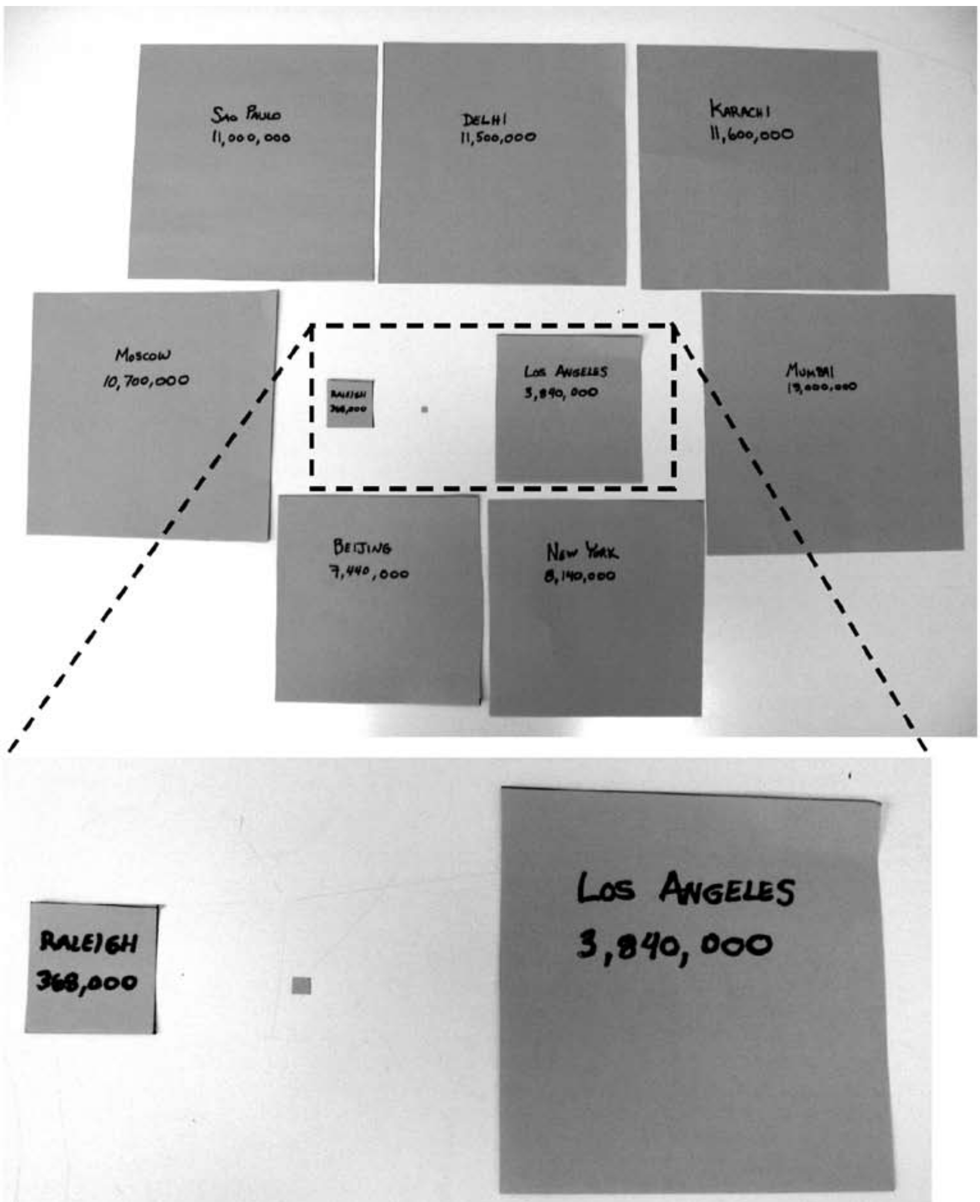
FIGURE 1.

Part B: Paper cities. Each square represents the population of the respective city. The small, unlabeled square in between Raleigh, North Carolina, and Los Angeles, California, is the small town of Hillsborough, North Carolina, population 5,450.



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In Part C, Paper Countries, students will repeat the same type of exercise, but this time they will be cutting out square areas that represent the physical areas of each of the listed countries. Again they will need to determine a scaling that will allow them to make paper countries large enough to be able to compare the largest and smallest. Emphasize that in this exercise the paper countries are representing the actual physical size of the countries rather than population. The students then cut out little "tokens" from notebook or construction paper to represent chunks of population. They will have to determine for themselves an appropriate scale for the number of people each population token will represent. Note that the countries listed vary considerably in area and population. Initially you should have the students exclude the two smallest countries, as they would otherwise have to choose a scale for population tokens that would require dozens and dozens of tokens for the largest countries (which would be interesting but time-consuming). The same exclusion should initially be made for the oil consumption tokens. For a more challenging version of this exercise, have them include all of the countries listed.

For example, if all the countries are included, the population token should represent the population of the smallest country listed, in this case, Iceland, with roughly 300,000 people. If one population token equals 300,000 people, Iceland will have one, Ghana will have 76, and China 4,400! Though that is probably not practical, it is a revealing exercise just to calculate the number of population tokens that would be required. Help students understand that this means that China's population is almost 5,000 times larger than Iceland's.

The scalings that are recommended in Student Data Sheet will provide the results shown in the box below. Note that the population and oil numbers for Canada and Ghana will result in much less than one token. For all other countries the values have been rounded to the nearest token. You can either leave Canada and Ghana out, or come up with a way of representing a fraction of a token (see Figure 2 on p. 114).

Country	Paper Country Area (cm^2)	Paper Country Length of Side (cm)	Population Tokens	Oil Tokens
China	380.0	19.6	13.0	7.0
India	131.0	11.5	11.0	2.0
EU	173.0	13.1	5.0	15.0
USA	393.0	19.8	3.0	21.0
Canada	399.0	20.0	0.3 (one-third)	2.0
Ghana	9.5	3.1	0.2 (one-fifth)	0.04

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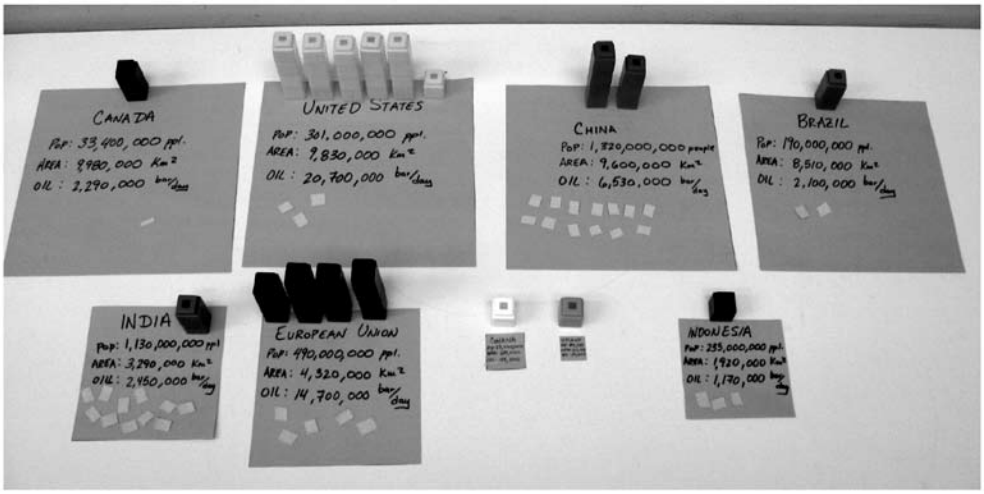
FIGURE 2.
Part C. Paper countries. The large paper squares represent the total land area of each country. The small paper squares represent the population of each country (each small square equals 100 million people). The stacked tokens represent oil consumption. Each token represents 1 million barrels per day.



Explore and Extend

Have students conduct web research on the population of their state compared with, or contrasted to, those of neighboring states. Have them create a graph of the populations of the states. This kind of exercise may provide surprising results. Did you know that California has 35 million people? Does any state have less than a million people? What range of powers of ten do the populations of states cover?

Below are some examples of other statistics to research. Answers may vary.

- Do more people live in the greater Tokyo metropolitan area or in all of Canada?
- Do more people live in Atlanta, Georgia or in all of Alaska, Wyoming, and Montana combined?
- Do more people live in greater London or in the state of North Carolina?
- How many people live in Africa? Asia? Europe?
- Have students calculate the per capita usage of oil for each country listed in the exercise in Part C of the Student Data Sheet.

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Evaluate

Check for student understanding:

Have students answer the questions at the end of the Student Data Sheet. These questions involve both quantitative comparisons between numbers and exploration of the range of powers of ten that different population contexts cover. Most of the questions can also serve as provocative starting points for class discussion on population, population density, and energy use in today's world and how each relates to the future.

Answers to Questions:

1. **How large are the populations of the largest cities in the world?**

   Answer: Around 10 million people.

2. **How many people live on the Earth?**

   Answer: Somewhere between 6 billion and 7 billion people (just knowing the world's population is several billion people is much better than not knowing it at all).

3. **How many people live in the most populated countries in the world? What are the countries?**

   Answer: Around 1 billion; China and India.

4. **How many people live in the United States?**

   Answer: Around 300 million.

5. **How many people live in your state?**

   Answer: *http://en.wikipedia.org/wiki/List_of_U.S._states_by_population*

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Student Data Sheet

Billions of Us: Scale & Population

How big is the biggest city in the world? How does it compare to the biggest city in the United States? How does it compare with your town?

Part A. City Scales

Take a look at the table below that lists the cities with the largest populations. Note that this ranking is for true city populations (population within the city limits*). The top five cities are ranked along with New York (#13), Beijing (#17), and Los Angeles (#42). Also included are two small North Carolina cities for comparison. In the two rows at the bottom, add your city and another city in your state. Find out the populations of those cities and enter in the population column.

World Ranking	City	Population in City Limits
1	Mumbai, India	13,000,000
2	Karachi, Pakistan	11,600,000
3	Delhi, India	11,500,000
4	Sao Paulo, Brazil	11,000,000
5	Moscow, Russia	10,700,000
13	New York City	8,140,000
17	Beijing, China	7,440,000
42	Los Angeles	3,840,000
?	Raleigh, NC	368,000
?	Hillsborough, NC	5,450
?	(your city)	
?	(another city in your state)	

*If entire metropolitan areas are included, the list is different and the populations are correspondingly larger. For example, the two largest metropolitan areas are currently Tokyo, with over 35 million people, and Mexico City, with over 19 million people. Source of population data: *http://en.wikipedia.org/wiki/List_of_cities_by_population#_note-WG*

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Part B. Paper Cities

On a clean sheet (or several sheets) of notebook or construction paper, you will outline squares whose areas represent the population of several of the cities. Be sure to include your city as well as one of the big cities. Remember that the area of your square is the length times the width. Cut out each of your cities and label them.

Hint: You will need to choose a scaling to begin. You probably want to make the area of the biggest city correspond to the largest square you can make with your paper. That will set a scale (say 20 cm × 20 cm or 400 cm^2 corresponds to the population of Mumbai). Use three significant digits for your numbers.

- The population of Mumbai (13,100,000) corresponds to 400 cm^2
- So 1 cm^2 = 32,800 people
- So what is the area of a paper city representing New York? Hillsborough, North Carolina?

City	Population	Area of Paper City	Width of Your Square City (cm)

Keep in mind that your scaling can be different. If you have big pieces of paper, or if you combine pieces, you can make your city squares bigger.

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Part C. Paper Countries: Area, Population, Energy Consumption

In this exercise you will compare the actual physical area of countries, their populations, and their energy consumption, by making small models representing each variable.

Exercise

1. Country Area: Cut out square pieces of paper that represent the areas of each of the countries below. You will need to choose a scaling (see scaling hints below). The largest countries (the United States, Canada, China) should have areas close to the size of a full sheet of paper.

2. Country Population: We will represent the population of each country with population tokens. Cut out little square or circular pieces (perhaps ½ inch to 1 inch on a side) or 1 inch paper dolls to represent population. You will need at least 20 of these (probably more). One idea is to cut out little circles and draw stick figures on them to represent people. Each one of these population tokens will represent a certain number of people. A good place to start is to make each token worth 100 million people (100,000,000). Place the correct number of population tokens on each country's sheet. Spread them out so you can see each token. For example, if you choose 100 million people per population token, the European Union will have 5 (rounding 490 million up to 500 million).

3. Oil Consumption: Choose small, stackable objects such as pennies, small blocks, or Legos to represent oil consumption. These pieces should be uniform in size (all the same for every student). These will be your oil tokens and will represent a certain scale of oil consumption. A good starting point is to have each oil token represent 1 million barrels of oil per day. Determine how many oil tokens each country uses and stack them on the country.

4. Whole World: Make one sheet whose area represents the area of the whole world. You will probably need to attach sheets together with a stapler or tape to make the area large enough (keep the same scaling as you used in Part A). Also repeat steps B and C.

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Student Data Sheet

Billions of Us: Scale & Population

Rank	Country	Population	Area (sq km)	Oil Consumption (barrels /day)
1	China	1,320,000,000	9,600,000	6,530,000
2	India	1,130,000,000	3,290,000	2,450,000
3	European Union	490,000,000	4,320,000	14,700,000
4	United States	301,000,000	9,830,000	20,700,000
5	Indonesia	235,000,000	1,920,000	1,170,000
6	Brazil	190,000,000	8,510,000	2,100,000
38	Canada	33,400,000	9,980,000	2,290,000
50	Ghana	23,000,000	239,000	44,000
178	Iceland	301,000	103,000	20,600
	World	6,600,000,000	510,000,000 (total) 150,000,000 (land)	82,600,000

Source: All data in the table above from the Central Intelligence Agency's *World Factbook* and rounded to three significant digits: *www.cia.gov/library/publications/the-world-factbook/rankorder/2119rank.html*

Scaling Hints

As in the previous exercise, you will have to choose a scaling for each parameter (area, population, and oil consumption).

Example scaling:

- Area: 10,000,000 sq km : 400 sq cm (20 cm × 20 cm); 1 sq cm = 25,000 sq km
- Population: 100,000,000 people = 1 population piece
- Oil Consumption: 1 million barrels = 1 oil barrel piece (a penny, a Lego)

Population Questions

1. How much smaller is your town than the largest city in the world?

2. How many powers of ten do the populations of cities cover?

3. How many powers of ten do the populations of countries cover?

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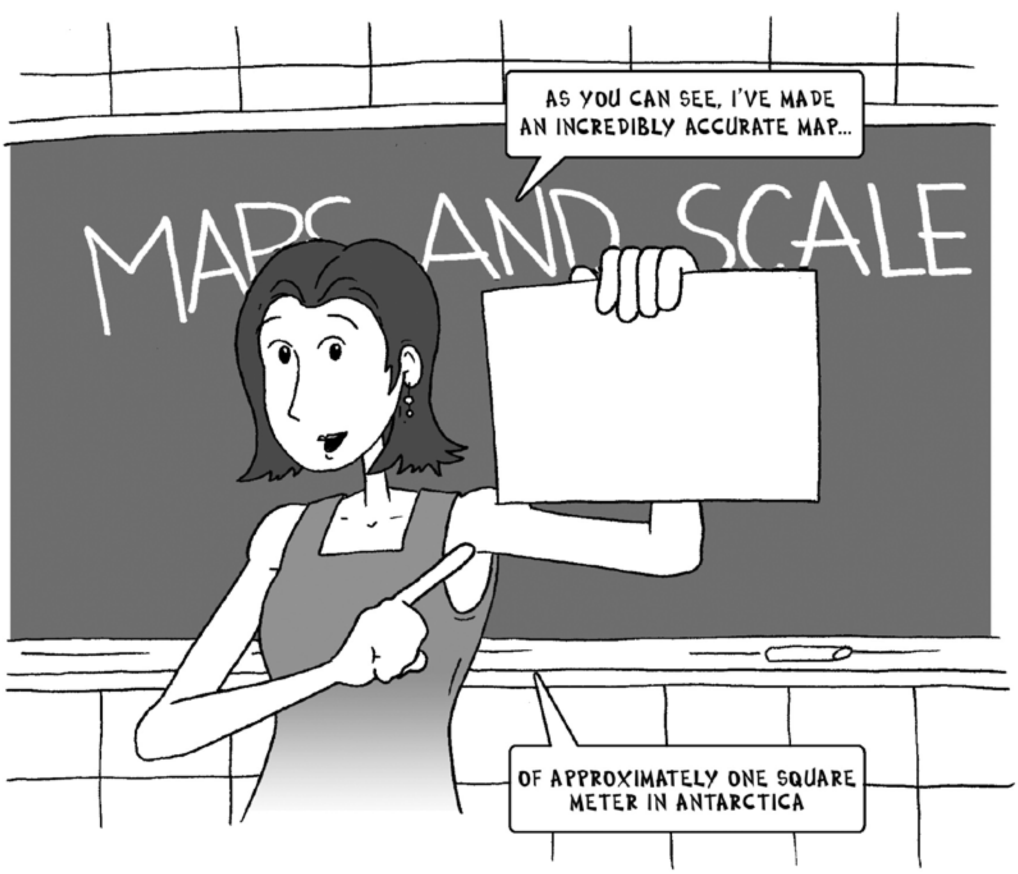
4. Which country has the highest population density? The lowest?

5. Which country uses the most oil per person? The least?

6. What fraction of the total world population lives in the United States? China? India?

7. For what fraction of total world oil consumption is the United States responsible? China?



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Chapter 15

That's Hot! The Effect of Size on Rate of Heat Loss

Overview

Through the use of common household items such as aluminum pans and thermometers, students will investigate how the size and shape of an object affect the rate of heat loss from the object to the environment This lesson is relevant to biology, as it relates to the size and shape of animals, their metabolism, and their ability to live in very cold or hot environments. A rate of heat loss that is too fast or too slow may affect the survival of an organism. By modeling different shapes and sizes of organisms using containers of various sizes, students explore how these variables affect the rate of heat loss.

Objectives

- To develop skills in observation.
- To use observations to make inferences about how size affects the rate of heat loss.

Process Skills

- Observing
- Predicting
- Comparing and contrasting
- Collecting data
- Analyzing data

Activity Duration

90 minutes

(Extension may take additional time.)

Background

Could a hamster live in Antarctica? Organisms that must regulate their body temperatures automatically release heat into the environment. Any loss or gain of heat occurs through the outermost surface of the animal (i.e., the skin). The requirement of organisms to strike a balance between the heat transferred to the environment through the skin and the heat generated within their bodies by their metabolism, is one way in which the size and shape of organisms are optimized and in some cases limited.

Even though metabolic mechanisms are similar among all types of organisms, the rate of metabolic regulation may vary greatly. A hamster's metabolic rate is significantly faster than the metabolic rate of a rhinoceros. One reason for the great difference is the larger surface area-to-volume ratios in the smaller mammal.

A warm-blooded animal's body (when healthy) is in thermal equilibrium, meaning that

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its body temperature remains constant. For this to occur, the heat generated within the animal through metabolic processes must equal the amount of heat leaving the animal through its surface (skin). The heat generation happens within the bulk or volume of the animal, and the heat transfer to or from the environment happens at the surface. When the temperature of the environment (air) changes to extreme levels, the animal's metabolism adjusts such that the heat equation remains balanced.

As a very small mammal, the hamster has a surface area-to-volume ratio that is very large. This means that the surface effect of heat transfer to (or from) the environment is quite large relative to the capacity of the hamster's small body volume to generate heat to compensate. A hamster therefore has a relatively high metabolic rate, resulting in high heat generation to maintain this balance. An elephant or a whale, on the other hand, has an enormous volume. Its surface-to-volume ratio is low. The rate of heat loss is easily compensated by the bulk metabolic processes, and therefore metabolic rates of those animals are correspondingly slower. So the connection between metabolic rate and the body size of an animal comes down ultimately to the surface-to-volume ratio!

The importance of the size and shape of an object to the rate of heat transfer to the environment holds for all objects, not just living ones. For example, two different bodies of water (e.g., lakes and ponds) will lose heat at different rates depending on their size and shape. A pond that is very deep and narrow will lose heat more slowly than a pond of the same volume that is wide and shallow. In the design of engines or high-power electronic components that get very hot, heat transfer fins are often used to increase surface area and enhance air cooling. Surface-to-volume ratio and its relation to heat transfer and temperature regulation are important in living, nonliving, and technological contexts.

Materials

Each group will need:

- 2 thermometers
- 1 pan (9 × 4 × 3 in.)
- 1 pan (13 × 9 × 2 in.)
- Hot plate
- Two 500 ml flasks or beakers
- Pair of hot mitts
- Safety goggles
- Access to water
- Timer or stopwatch
- Graph paper
- Colored pencils

Example of two pans of different sizes.

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Note: Depending on the size of the class, groups may share hot plates. For younger students, the teacher may want to pour the hot water into the pans for each lab group.

For the Engage portion of this activity, the labels of continents and cards with animals should be prepared before the first day of the activity.

Engage

Make a label on card stock for each of the seven continents. Before class begins, place the labels around the room. As the students enter the classroom, hand each student an index card with a name and picture of an animal. Ask them to tape the card underneath the continent on which they think the animal lives. Have the students discuss why they placed the animals in those locations. Have them brainstorm why certain animals live on certain continents.

Seven Main Continents	Examples of Organisms
Asia	Panda, elephant, small-clawed otter
Africa	Elephant, cheetah, meerkat, giraffe, zebra
North America	Prairie dog, cougar, wolf, bison
South America	Jaguar, chinchilla, Brazilian tapir
Antarctica	Penguin, seal, Arctic tern
Europe	Norwegian lemming
Australia	Koala, kangaroo, platypus

African elephant

Asian elephant

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After discussion of where and why certain species of animals have adapted to their climates, show the class pictures of Asian elephants and African elephants. Have the students compare and contrast the characteristics of the two. The students will eventually notice that the ears of the two elephants are different in size. The ears of the African elephant are much bigger and may reach a length of about 5 feet from top to bottom. The huge ears of the African elephant function not only for hearing but also for ventilation, visual communication, and heat transfer. The size difference in the ears of the two elephants can be linked partly to their climates. African elephants live near the equator, where it is warmer; they have bigger ears (increased surface area) to aid in heat loss. Note that the large, flat ear is perfectly optimized for heat transfer. Like a piece of paper, it has a huge surface-to-volume ratio compared with the rest of the body of the animal. Asian elephants live farther north, in cooler climates; they have smaller ears (smaller surface area) to reduce heat loss.

Note: Older students could also research the various scientific rules that apply to climate, body size, and heat loss, such as Allen's rule (organisms from colder climates have shorter limbs than similar animals from warmer climates), Bergmann's rule (the body mass increases with latitude for a particular species), and Gloger's rule (darker-pigmented forms of an organism tend to be found in more humid climates, such as equatorial environments). There are several other rules that may apply not necessarily to heat loss but to scaling issues in general.

Explore

Now explain to the students that they will investigate how the size and shape of an object may affect the rate of heat loss. In lab groups, have the students discuss whether or not the shape and size of the container should have an effect on the heat loss of water in the container and why. Then have them formulate a hypothesis based on this discussion. They should record their hypotheses on the Student Data Sheet.

In their lab groups, the students will investigate how the size and shape of two different containers affect the rate of heat loss. Older students should boil 1,000 ml of water. (The teacher may want to boil and pour the water for younger students.) Before the water is at a rapid boil, carefully pour 500 ml of water into the large container and the other 500 ml of water into the small container. Gently place a thermometer face up in bottom of each container. Warn the students that the water is very hot and that care should be taken when handling pans, thermometers, and water.

The students should *immediately* take the *initial* temperature of the water in each container and record the data in the table provided on their Student Data Sheet. The students should then take a reading on the thermometers one

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minute after the water has been poured into the pans and then continue to measure the temperature every minute for five minutes. After the five-minute data collection, have the students calculate the change in temperature using the following formula:

$$\Delta T = (\text{Final Temperature} - \text{Initial Temperature})$$

Have the students also determine the overall rate of temperature loss or "cooling rate." This is simply the number of degrees per minute that were lost for each pan:

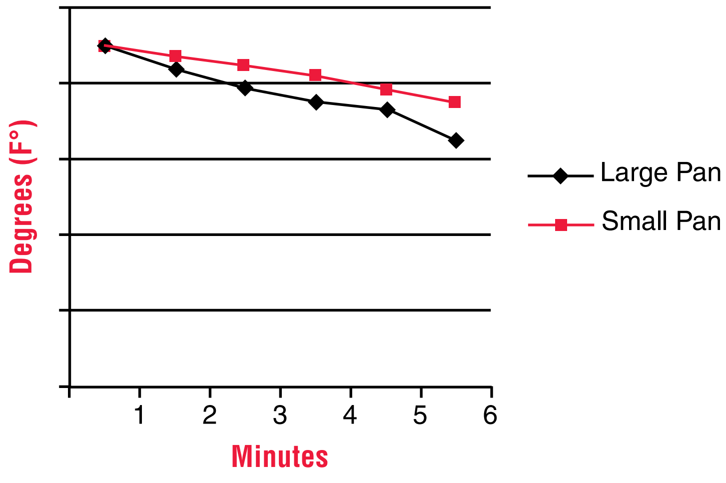
$$\text{Cooling Rate} = \Delta T/\Delta \text{time}$$
$$= (\text{Final Temperature} - \text{Initial Temperature})/\ (\text{Final Time} - \text{Initial Time})$$

Since the initial time in this exercise is zero minutes, the above equation simplifies to:

$$(\text{Final Temperature} - \text{Initial Temperature})/\ (\text{Final Time})$$

The cooling rate is expressed as "degrees per minute" or (°F/min.). In this case, since the water is cooling, the rate will be negative (since ΔT is negative).

Each group should then plot their data on graph paper using colored pencils. Students should use one color for the data collected from the large pan and another color for data collected from the small pan. Once all groups have completed the graph, have the students discuss their answers to the Conclusion questions on their Student Data Sheets and be ready to report their findings to the rest of the class (see the example of a student graph below). Note that the overall cooling rate that the students calculate is simply the slope of these graphs.



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Explain

As each lab group reports their results to rest of class, record the similarities and differences between groups on the overhead or blackboard. Ask the students to analyze the results of the entire class. If there are groups with findings different from those of the majority of the class, have the students brainstorm why some groups may have different results. They may suggest different types of error, including human error, broken equipment, unequal amounts of water, too much time between recording temperatures, and so on. At this point, you may also review the importance of a controlled experiment and various ways of improving the investigation.

Both pans had the same volume of water and very close initial temperatures. The large pan had more surface area exposed to the air and so has a higher rate of heat loss. Not only is more water surface exposed to air, but more is also exposed to the pan (which is metal and a great thermal conductor). The smaller pan had less surface area exposed to the air, resulting in a slower rate of heat loss. This investigation models how smaller animals (with higher surface area-to-volume ratios) lose heat faster than larger animals (with smaller surface area-to-volume ratios).

Extend

Since this investigation explored only the difference in surface area while keeping the volume constant, have the students design a similar investigation that looks at differences in surface area *and* volume. In their lab groups (or as a class), have the students decide what materials they will need to complete this investigation, as well as the procedure and safety precautions necessary to carry out the experiment. Complete the experiment and discuss the results.

Evaluate

Check for student understanding:

1. What are surface area-to-volume ratios? Give an example.
2. How does the surface area-to-volume ratio affect the rate of heat loss of a pond?
3. How does the size of an organism affect the rate of heat loss?
4. What are some adaptations of animals to deal with hot and cold climates?

For other activities or information about heat loss:

- *www.courseworkhelp.co.uk/GCSE/Science/11.htm*
- *www.faqs.org/docs/Newtonian/Newtonian_44.htm*

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Student Data Sheet

That's Hot!

Name ______________________________

Problem

Do the shape and size of the container have an effect on heat loss of water in the container? Which container will cool more quickly?

Hypothesis

____

____

SAFTEY PRECAUTIONS
***Remember to wear goggles and be careful not to touch the hot water, hot glassware, or hot plate.**

Procedure

1. Let 1,000 ml of water come to a slight boil. Using hot mitts, carefully pour 500 ml of water into the large container and the other 500 ml of water into the small container.
2. Gently place a thermometer face up in the bottom of each container without touching the water!
3. Take the initial temperature of the water in each container and record in the data table.
4. Take a reading on the thermometers one minute after the water has been poured into the pans. Record the temperature in the data table below. Do not remove the thermometers from the water.
5. Continue to measure the temperature every minute for five minutes. Remember to record the temperatures in the data table.
6. Calculate the change in temperature using the formula under the data table.
7. Determine the overall rate of temperature loss using the formula under the data table.
8. Using graph paper and colored pencils, plot your data on a line graph.

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Student Data Sheet

That's Hot!

Data Table

Time (Minute)	Temp. of Water in Large Pan (Celsius)	Temp. of Water in Small Pan (Celsius)
Initial		
1		
2		
3		
4		
5		
ΔT = Tf-Ti		
Cooling Rate		

ΔT = (Final Temperature – Initial Temperature)

Cooling Rate = $\Delta T/\Delta$time
= (Final Temperature – Initial Temperature)/(Final Time – Initial Time)

Since your initial time is 0 min., this simplifies to
= (Final Temperature – Initial Temperature)/(Final Time)

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Conclusion

1. **Examine the data for the five time periods. Was your hypothesis supported or refuted?**

2. **Write a few sentences summarizing the answer to the problem statement according to your data.**

3. **How could you improve this investigation?**

4. **Apply the results of this investigation to similar processes found in living organisms.**

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