Genome: Unlocking Life's Code

Educator's Guide

for Teachers of Grades 7–12

GENOME
UNLOCKING
LIFE'S
CODE

National Human Genome Research Institute

Smithsonian
National Museum of Natural History

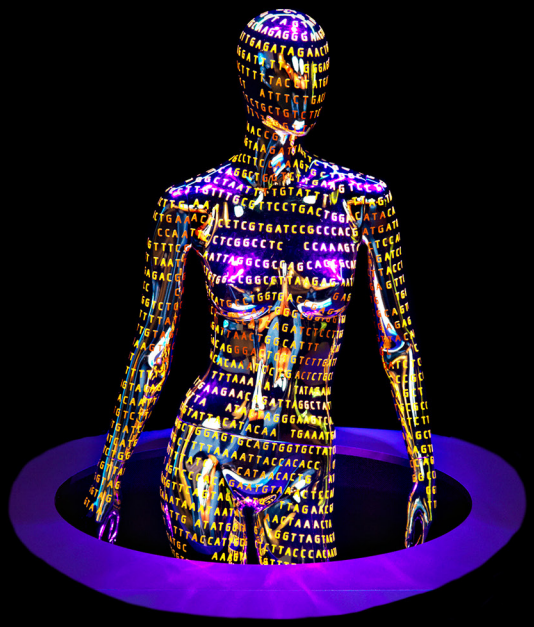

Photo: Donald E. Hurlbert and James Di Loreto, Smithsonian Institution

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What the Exhibit Offers

Genomics—the study of the entire genome of an organism—is a cutting-edge field of study that is going to impact our lives in dramatic ways. It is important that students understand what genomics is and what it teaches us about ourselves and the rest of the natural world. The exhibit *Genome: Unlocking Life's Code* actively engages students in key issues and topics related to genomics. It provides a place to explore:

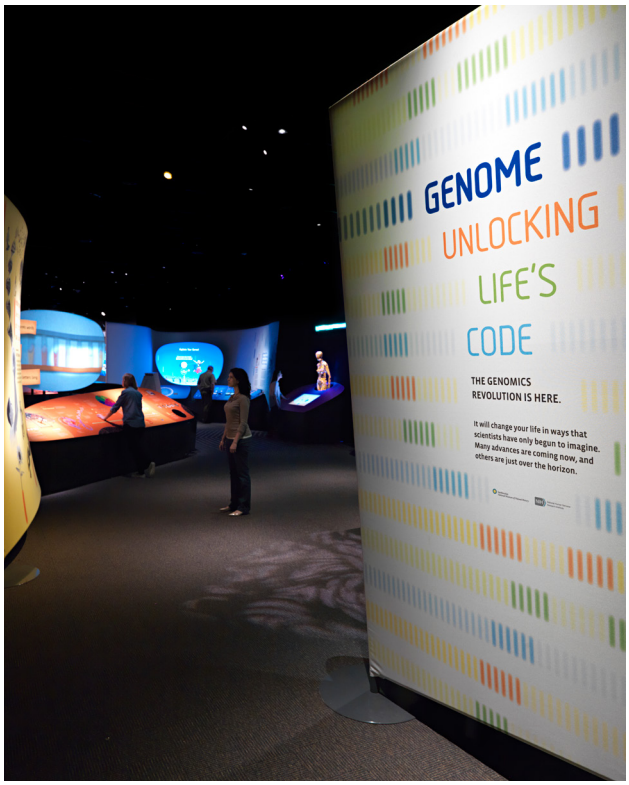
- what the genome is, the scale of the genome, and how it is structured
- what the human genome reveals about health and the risk of disease
- how sequencing the human genome has revolutionized the way we look at our ancestry and ourselves
- ways genomics has enhanced our understanding of the natural world around us
- how the science of genomics may affect them personally

We hope that this exhibit experience will not only help your students better understand genomics, but also instill a sense of excitement about genomics and careers in science.

What This Guide Offers

This guide contains basic information and strategies for using the exhibit to introduce middle grade and high school students to the genomics revolution and what it means to them. Links direct you to additional information and resources on the exhibit website, http://unlockinglifescode.org/.

We have provided activities for you to use with your students before you visit the exhibit, while you are in the exhibit, and back in the classroom. The resources listed at the back of the guide provide opportunities to extend your investigations.



Genome: Unlocking Life's Code entrance at the National Museum of Natural History
Photo: Donald E. Hurlbert and James Di Loreto, Smithsonian Institution

Pre-Visit and Post-Visit Assessment

The Personal Genomics Education Project developed Map-Ed (http://www.pged.org/maped/), a fun interactive web application that educators can use to assess student understanding of Personal Genomics. Students answer five multiple-choice questions about genetics and genomics and then pin themselves on a world map. The exhibit *Genome: Unlocking Life's Code* covers the key concepts behind Map-Ed's five questions:

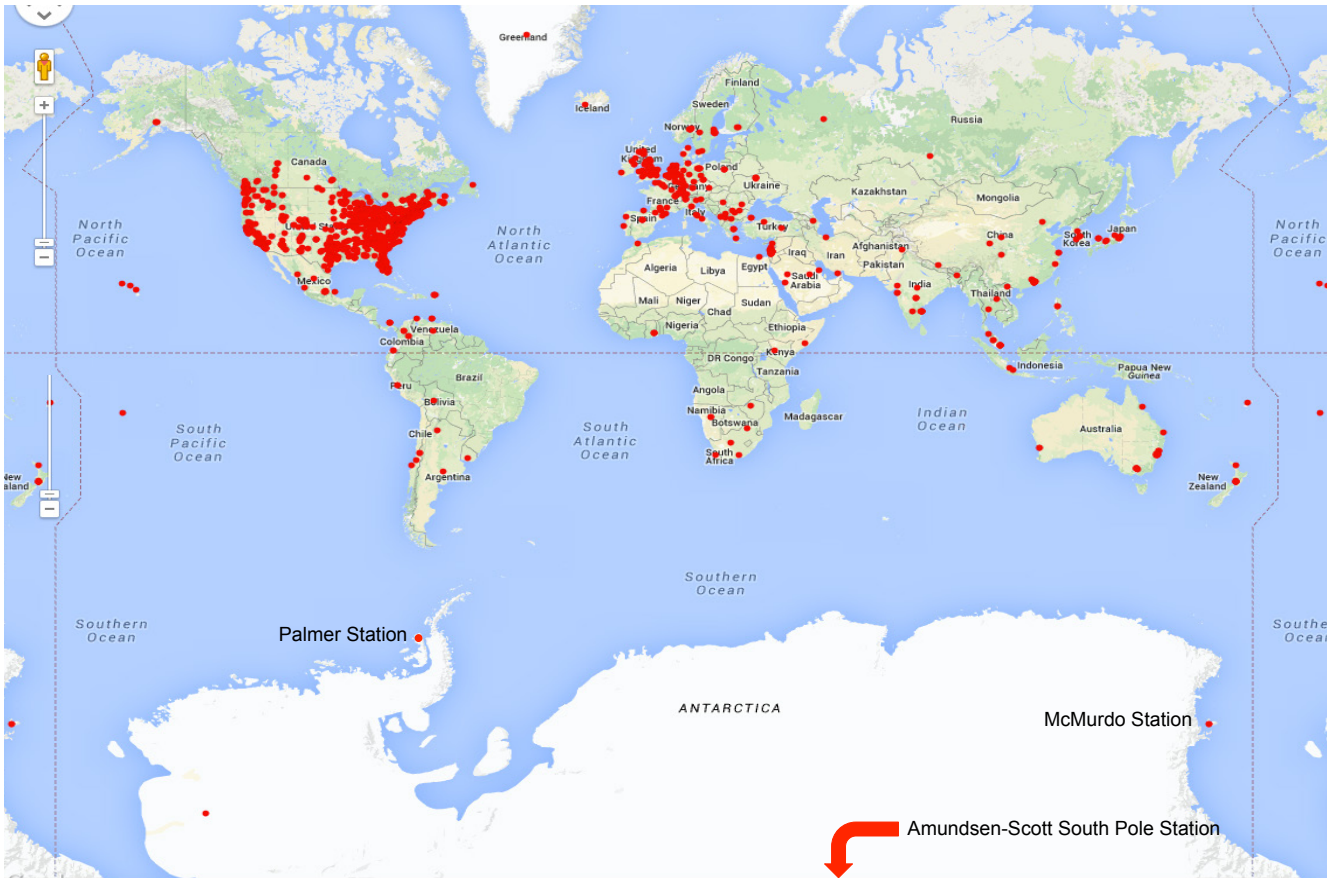
1. Do your genes determine everything about you and your future?
   a. Yes
   b. No

2. Pick any 2 people in the world. What percentage of their DNA sequence is the same?
   a. ~10%
   b. ~50%
   c. >99%

3. What is a mutation?
   a. A mutation is simply a change in one's DNA sequence and is not necessarily bad or good.
   b. A mutation is a bad thing and usually causes disease.
   c. Healthy people do not have mutations.

4. Can some mutations be beneficial?
   a. Yes
   b. No

5. Can your genes influence how well certain medications will work for you?
   a. Yes
   b. No



Map-Ed has accumulated over 2,700 pins spread over all seven continents, including Antarctica. Add your classroom to the map!

EXHIBIT CONTENT

Genome: Unlocking Life's Code celebrates the 10th anniversary of the Human Genome Project's landmark achievement—the first complete sequencing of the human genetic code. Advances in technology, which started in the 1990s, led to a revolution in genomic research that resulted in the complete sequencing of the human genome in 2003. That revolution continues today in the application of genomics to our understanding of human health, ourselves, and the natural world.

The Big Ideas

Contained within the cells of every living thing, the genome is a complete set of instructions for how to grow and live.

- The completion of the first human genome sequence in 2003 resulted from a revolution in biotechnology that is going to affect us all.
- The science of genomics offers new ways of looking at our health, our risk for disease, and the ways our genes interact with each other and the environment.
- Genomics shows us how we are alike, how we are unique, and how we are related to all life on Earth, past and present.
- Advances in genomic science raise complex personal, social, and ethical issues.

The three major sections of *Genome: Unlocking Life's Code* cover the following basic content about the genomic revolution.

The Genome Within Us

Meet Your Genome

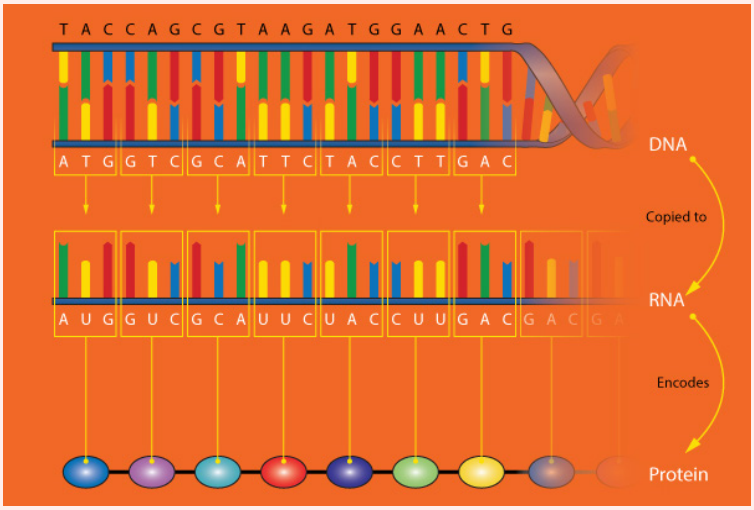
The genome is a complete code of instructions for how to grow and live. Every living thing has a genome with a unique sequence of DNA. Humans share part of their genome with all life on Earth.

The human genome is written in the spiraling, ladder-shaped molecule known as deoxyribonucleic acid, or DNA. It is written in four basic chemicals:

- adenine (A)
- cytosine (C)
- guanine (G)
- thymine (T)

Those chemicals form the rungs of the DNA ladder. C always pairs with G, and A with T. Strung together in a sequence of billions of pairs, these four chemicals serve as building blocks for the DNA that makes up the human genome. They are translated into amino acids that in turn form proteins. A complete and identical copy of each individual's DNA, with all of the approximately 20,000 genes, is coiled within the nucleus of every cell in his or her body.

Every human inherits slight differences, or variants, in his or her genome. These variants affect traits such as height, eye color, and hair texture, as well as risk of disease, personality, and even special abilities. They make each individual unique.



"DNA to RNA to Protein," Credit: Daryl Leja, National Institutes of Health

SIZE IT UP

The human genome is over 3 billion letters long.

- If you typed 360 letters a minute for eight hours a day, it would take you nearly 100 years to type all the letters.
- To print out all the letters, you would need 2,369 reams of paper, each containing 500 sheets.
- Stretched out, the human genome in one cell would measure 6 feet (1.8 m).
- Yet, despite its enormous size, the human genome folds up so small that a copy fits inside every cell in your body. Two hundred human genomes could fit on the head of a pin.

Reading Life's Code

It took more than a decade, a billion dollars, and an international consortium of scientists to complete the first human genome sequence in 2003. This achievement is a cornerstone of the revolution in biotechnology akin to the impact of the Internet on the way we communicate. It has led to major advances in diagnosing and treating disease and in understanding the ancestry of individual humans as well as our species as a whole.

Since the 1990s, the speed and accuracy of DNA sequencing technology has improved by leaps and bounds. Decoding a human genome once took years. Now scientists use machines that sequence a human genome in a matter of hours. To decode the entire sequence of billions of letters, some machines process the genome in segments and reassemble them in the right order. Others read long segments of DNA as they pass through a small pore.

Personal Genome Machine "ION TORRENT" IMGM Laboraties

Scientists are looking ahead to a future when we can apply the information contained in DNA in hundreds of new ways. Already faster, cheaper DNA sequencing machines put a powerful new tool for diagnosing disease within reach of many hospitals and clinics. Next-generation technology has helped revolutionize doctors' understanding of rare diseases and cancer and led to more effective treatments. As technology companies develop even more efficient ways of reading DNA, scientists will be able to harness the power of DNA in hundreds of new ways.

HOW CHEAP IS CHEAP?

Sequencing the first human genome cost $2.7 billion. In 2014, the cost of sequencing the human genome is estimated at $5,000. In 2003, a new Corvette cost $43,635. If the technology cost of manufacturing a car had decreased at the same rate as the cost to sequence the human genome, a new Corvette today would cost a dime.

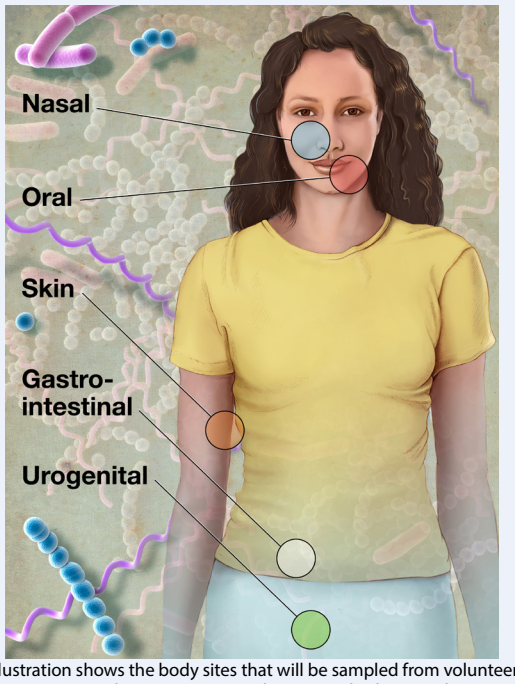
Health

Your Genome, Your Health

Genomics offers a new way of looking at our biology, health, and risk for disease. As scientists learn more about how genes, other parts of the genome, and the environment interact, they use this knowledge to improve healthcare. Genetic testing can help predict an individual's chances for many diseases. More affordable DNA sequencing may soon also give us the option of learning how our genomic makeup may influence our future.

If you compared two human genomes, you would find that about one in every 1,000 letters of the code differs. Most of these genetic variants are harmless. Some give people resistance to disease. Some are linked to serious disorders. However, lifestyle choices, diet, environment, and age also play a major role in human health. The risk for developing many diseases depends on a combination of factors including a person's genes, the way he or she lives, and sometimes just plain luck.

Genomic technology has revealed that trillions of microbes, each with its own genome, live in and on almost every part of the human body, outnumbering human cells 10 to one. This microbiome, which is constantly changing, manages critical tasks that keep us healthy, such as digesting food and keeping the immune system running smoothly. As researchers discover more about which microbes live where on the



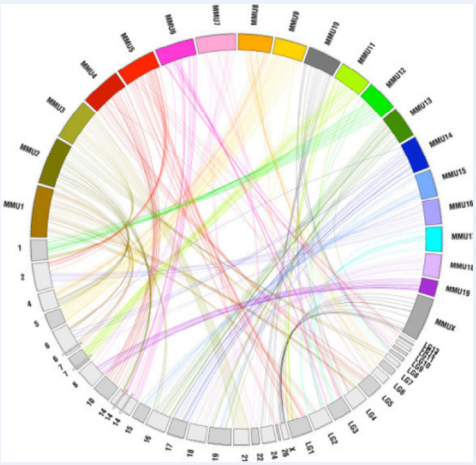
This illustration shows the body sites that will be sampled from volunteers for the Human Microbiome Project. Credit: NIH Medical Arts and Printing

human body, they will also learn how to restore the microbiome when people get sick.

▶ Next-Gen Medicine

Hardly a week goes by without a medical breakthrough enabled by genomics. This is just the leading edge of a new era in understanding the genome's role in disease. As researchers figure out more about how the genome works, they are discovering better ways to combat genetic disease, personalize drug treatments, and stop the spread of deadly infections.

As we age, environment and random mistakes in copying DNA change our genes, letting abnormal cells—including cancer cells—multiply.



Circos plots can give a snapshot of the mutations within a genome. The outer ring represents the chromosomes. The inner rings each detail the location of different types of mutations.
Credit: McGraw et al., 2011

Cancer is not one disease, but a family of hundreds of genomic illnesses marked by uncontrolled cell growth. By comparing the genomes of cancer cells with the genomes of healthy cells, scientists are learning more about what makes tumors grow, which in turn leads to new treatments for cancer. The Cancer Genome Atlas at the National Institutes of Health is cataloging all the genomic changes in nearly two dozen common cancers.

Genomic variants can also cause different individuals to have different responses to the same drug. In the future, with advances in genomic medicine and technology, tailoring drugs to an individual's genomic profile could become common. These advances may also lead to new ways of protecting humans against deadly parasites carried by insects and against pathogens that contaminate our food or cause hospital outbreaks of antibiotic-resistant bacteria.

Kissing bugs are attracted to the carbon dioxide we exhale and are the vector for Chagas disease.
Credit: Daniel H. Janzen

The Natural World

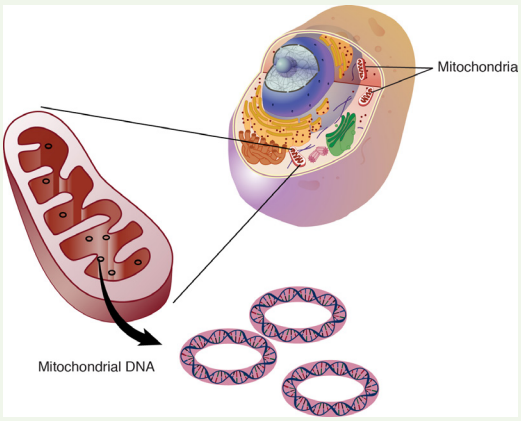
▶ Our Genomic Journey

Genomics is helping to expand the story of our own species, *Homo sapiens*, as pieced together from fossil and archeological evidence. It is also providing answers to questions about our relationship with ancient species such as the Neanderthals. Because our species evolved in Africa only about 200,000 years ago, the genomes of all humans living today are about 99.9 percent alike. The tiny amount of difference accounts for variations in our appearance and our risk for or protection from disease. It also reveals how populations of our ancestors adapted to changing environments as they moved across the world.

Homo neanderthalensis, adult male.
Credit: John Gurche

For example, as our species spread from Africa into northern latitudes, skin colors evolved with changing light. Genomics has revealed that many genes interacting with the environment influence differences such as skin color, facial features, and hair texture. There are no sharp boundaries dividing humans into distinct groups, or races. In fact, most genomic differences—especially common ones such as skin color—occur in every geographic population.

Genomics also helps us trace our ancestry. Since modern humans evolved, our genomes have been changing in small ways that link our ancestors to specific times and places. This story is written in our DNA. Mothers pass mitochondrial DNA (mtDNA) in their egg cells to both sons and daughters, preserving the link to the past through the female line. Fathers pass a copy of their Y chromosome to their sons. This allows men to trace their ancestry through the male line. The other 22 chromosomes come from both parents and carry many more regions of DNA from ancestors on both sides of the family.



Mitochondrial DNA is the small circular chromosome found inside mitochondria. The mitochondria, and thus mitochondrial DNA, are passed from mother to offspring.
Credit: Darryl Leja, National Institutes of Health

Discovering a World of Genomes

Recent advances in technology have given scientists the tools to sequence the DNA of every organism on the planet. With each new genome that is sequenced, scientists expand their understanding of biodiversity, the behavior of living things, and how species adapt to their environments and interact with each other.

Scientists compare genomes of different organisms to see how they are related, what characteristics the organisms share, and what makes each unique. This knowledge helps us better understand the process of evolution. Our connections to other species could be critical to our survival because many genes linked to human disease are also found in other organisms. In addition, DNA sequencing is beginning to play a key role in monitoring our planet's health and in providing clues to fighting everything from pollution to pests to human disease.

Researchers are discovering species they never knew existed, unraveling more of life's diversity, and showing what large-scale genome sequencing might accomplish. Smithsonian Institution scientists are currently working on sequencing the entire ecosystem of the Pacific Ocean island of Moorea by collecting representatives of every plant, animal, fungus, and algae species and then decoding their DNA.

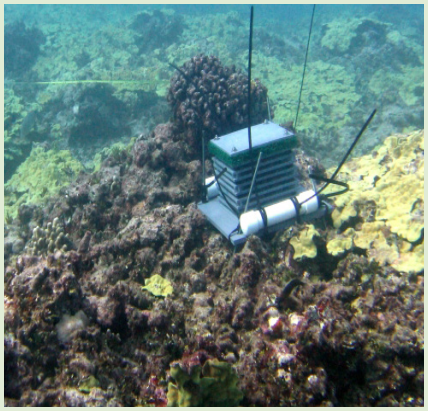
In 2011, the Smithsonian launched the Global Genome Initiative (GGI) to coordinate a worldwide network of research organizations involved in collecting and preserving tissue samples from species throughout the tree of life. With many species at the brink of extinction, preserving their genetic blueprints is more critical than ever.

Nitrogen freezers housed in the National Museum of Natural History's Biorepository. These freezers, along with others across the Global Genome Initiative, will be used to cryo-preserve 50% of the diversity of life in five years. Image by Donald E. Hurlbert, Smithsonian Institution

EXPLORE Q?rius

Q?rius (http://qrius.si.edu) is a free, non-commercial digital learning space designed by the Smithsonian Natural History Museum as a new way to connect science with everyday experiences. Its name was chosen for its power to inspire people with curiosity and excitement. Q?rius is a first-of-its-kind interactive and experimental learning space that brings the unique assets of the Smithsonian's National Museum of Natural History – the science, researchers, and collections – out from behind the scenes.

Reefs unleashed is an on-line activity students can complete that lets them experience research in which scientists sample biodiversity by sequencing entire ecosystems, like the island of Moorea. Students hear insights from marine biologist Nancy Knowlton and then try and identify the animals that moved onto a plate from an autonomous reef monitoring structure (ARMS). Next students compare the physical and morphological characteristics of organisms for similarities with and differences to known species. Christina Castillo then explains how DNA can reveal what the eye missed. The activity ends with a video of Chris Meyer explaining more about how new technologies like ARMS and DNA sequencing are changing our understanding of ocean biodiversity.



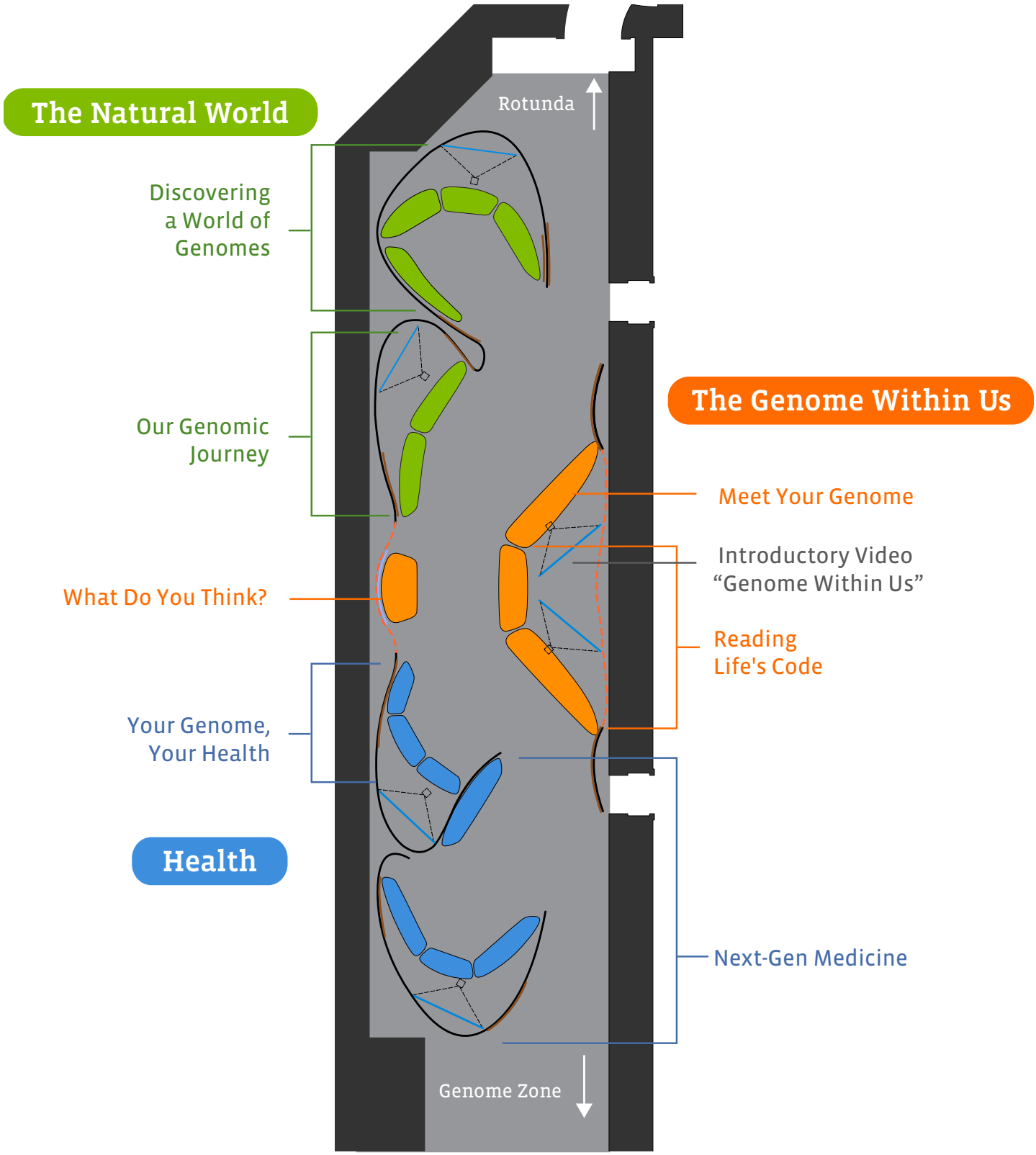
Autonomous reef monitoring structure (ARMS) on the bottom of the ocean floor. Image by NOAA

Researchers sort the specimens they collected on the island of Moorea. The researchers will determine the DNA bar code for each specimen. Credit: Chris Meyers

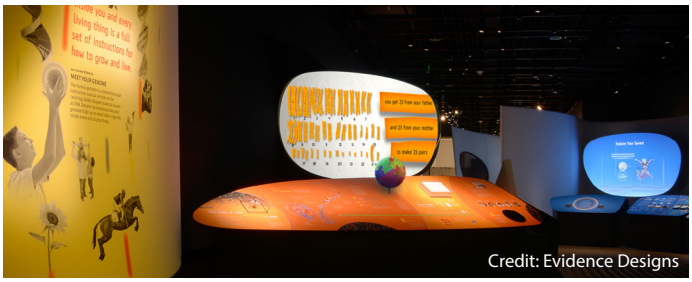
EXHIBIT FLOOR PLAN

The following pages describe what students can do in each of the exhibit areas. You can also take a virtual tour of the exhibit.

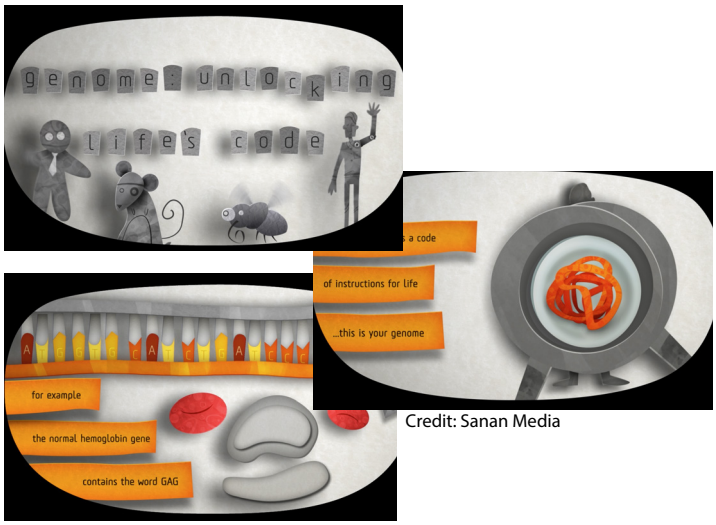
The floor plan below orients you to the exhibit on display at the Smithsonian's National Museum of Natural History. The exact layout of the exhibit's three major sections may be altered at different museums.



Introductory Video


Credit: Evidence Designs

- A large overhead video provides a dramatic introduction to the human genome.
- The 5-minute presentation explains what the human genome is, what it contains, where it's located, how it works, and what impact its sequencing is having.



Credit: Sanan Media

The Genome Within Us

Meet Your Genome

The displays and activities in this section provide a basic toolkit of information about the genome and DNA.

Students can:

- See real DNA extracted from salmon sperm.
- Examine graphics illustrating the structure of the genome and DNA.
- Explore the size of the genome and DNA.
- Look in a mirror to identify physical traits they inherited through genes passed on from their parents.

Reading Life's Code

This section focuses on the history of discoveries about DNA and the human genome—leading to the completion of the first human genome sequence in 2003 and the revolution in technology and research.

Students can:

- Examine a timeline of major achievements in learning about the human genome.
- Watch video clips in which renowned scientists reflect on challenges and achievements related to genomics, and on what the future may hold.
- Try their hand at aligning a DNA sequence from the gene for hemoglobin.
- See examples of machines that now sequence DNA in just a few hours.

President Bush signs H.R. 493, the Genetic Information Nondiscrimination Act (GINA) of 2008, in the Oval Office. Credit: Eric Draper, The Whitehouse

What Do You Think?

Two media pieces focus on genomics in the news and some of the thorny issues raised by the genomics revolution.

Students can:

- Watch a digital readout of the latest news stories about genomics.
- Answer questions about ethical issues related to genomics in the interactive "What Do You Think?" and compare their answers with those of other visitors.

Issues students will consider in "What Do You Think?" Include:

- Are there any questions genomic scientists should not be able to study?
- Should we place limits on genetic research?
- Should scientists be able to share genomic information with each other for research purposes?

Issues students will consider in "What Would YOU Decide?" include:

- Daniel is overweight. His parents, Mark and Anna, read an article about a genetic test that might point to a better diet for him. However, the article also says that the research is unsettled at this point. Should Daniel's parents have his DNA analyzed to help control his weight?

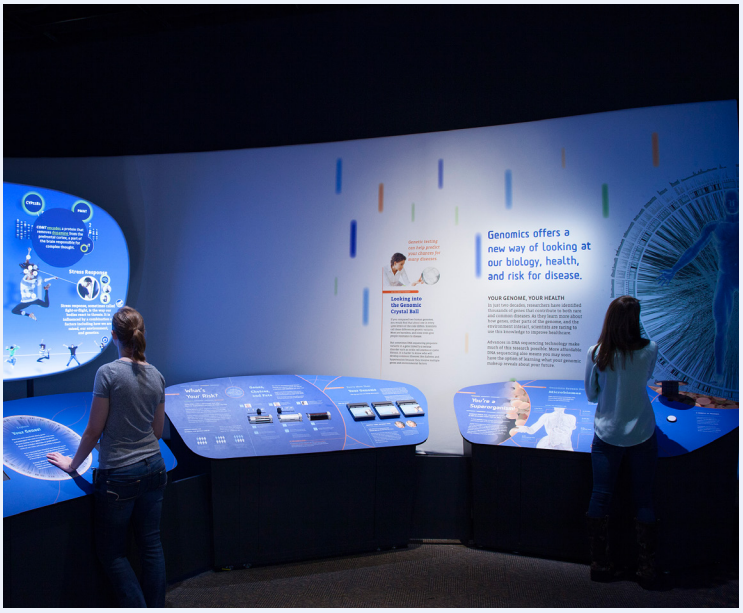


Photo: Don Hurlbert, Smithsonian Institution

Your Genome, Your Health

A variety of interactive experiences illustrate how genomics offers new ways of looking at human biology and health and predicting risk for disease.

Students can:

- Use the computer interactive "Explore Your Genes!" to find out which genes influence physical traits such as eye color or susceptibility to diseases like diabetes.
- Consider the factors that affect human health, and explore the interplay between genetic risk, chance, and environment.
- Find out what factors affect an individual's risk for diseases like breast cancer, lung cancer, and Huntington's disease.
- Play a True or False? Game about genes and the environment .
- Meet some of the trillions of microbes that live on our bodies, find out where they live, and look close-up at the microbes that typically live on our hands.

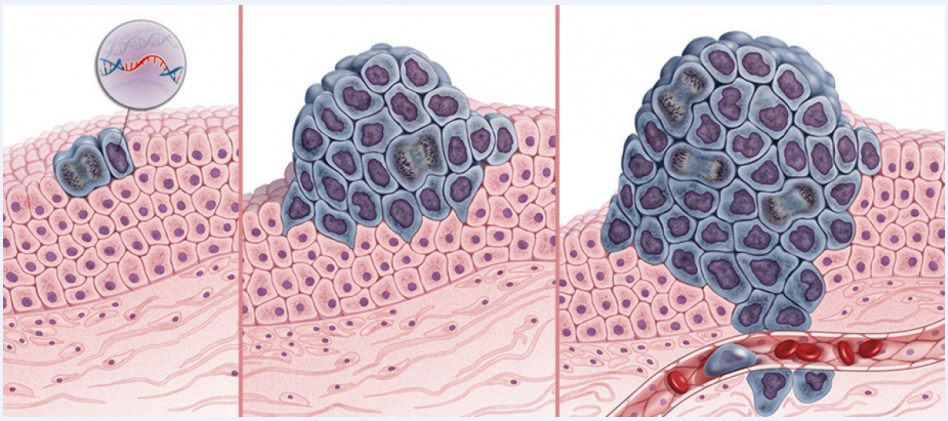
Spectral karyotype of the human genome Credit: Paul S Taylor

Next-Gen Medicine

This section provides an inside look at how genomic medicine has generated a revolution in understanding and treating disease and what it could mean for the future.

Students can:

- Explore a display that explains how cancer begins and how genomic medicine is leading to new treatments for cancer and to new drugs tailored to an individual's genomic profile.
- Watch the video "Solving Medical Mysteries" to hear three stories about people who have benefited from genomics and personalized medicine.
- Play "You're the Doctor" and make sure none of your patients have a genomic variant that causes a reaction to an antiviral drug.
- Find out how genome sequencing of each organism involved in the life cycle of a parasite is helping scientists stop the spread of deadly Chagas disease.
- Play the game "Genomics and Family: What Would YOU Decide?" to explore personal, social, ethical, and medical issues people may face with the advent of genomic medicine.



Cancer is a group of diseases characterized by uncontrolled cell growth. Cancer begins when a single cell mutates, resulting in a breakdown of the normal regulatory controls that keep cell division in check. These mutations can be inherited, caused by errors in DNA replication, or result from exposure to harmful chemicals. A cancerous tumor can spread to other parts of the body and, if left untreated, be fatal.
Credit: Darryl Leja, National Institutes of Health

Our Genomic Journey

This section highlights what genomics is teaching us about the story of our species and its journey around the world.

Students can:

- Follow the journey of our species, *Homo sapiens*, out of Africa and around the world in the interactive "In and Beyond Africa."
- Examine models of three Neanderthal fossils and a fossil from another group of ancient humans called Denisovans, and consider whether members of these groups ever met and interbred with our own species.
- Explore a display that shows how variations in traits such as skin color and lactose intolerance occurred as our ancestors moved around the world and adapted to changing environments.
- Visit the interactive "Exploring Our Genomic Ancestry" to find out what nine people learned about their ancestry by having their DNA tested.
- Find out how mitochondrial DNA and the Y chromosome help us trace our ancestry.

Photo: Don Hurlbert, Smithsonian Institution

Discovering a World of Genomes

Displays and interactives describe what scientists are learning as they race to unravel and preserve the genomes of many different organisms.

Students can:

- Compare columns that show the relative sizes of the genomes of humans and six other organisms in "How Genomes Measure Up."
- Find out how a Smithsonian researcher used DNA sequencing to identify what kind of bird caused a plane crash, then ID the bird that brought the plane down.
- Listen to recordings of zebra finch songs that illustrate the role a certain gene plays in speech.
- Look at a variety of species—from grapes to butterflies to the Tasmanian devil—and find out what genomics has helped us learn about each species.
- Compare the genome sequences of 15 different species and unravel the secrets written in heir DNA in the computer interactive "Reading Nature's Code."
- Visit a display that shows how Smithsonian scientists are working to sequence an entire ecosystem—including every plant, animal, fungus, and alga species—of the Pacific Ocean island of Moorea.

Researcher Carla Dove's lab at the National Museum of Natural History uses DNA barcoding to identify birds after collisions with airplanes.
Photograph by Timothy Devine

HOW GENOMES MEASURE UP

Amoeba:	670,000,000,000 base pairs number of genes unknown
Humans:	2,900,000,000 base pairs 20,000 genes
Barley:	5,100,000,000 base pairs 21,766 genes
Pufferfish:	400,000,000 base pairs 20,000 genes
Roundworm:	97,000,000 base pairs 19,000 genes
Baker's Yeast:	12,156,677 base pairs 6,275 genes
Mycoplasma:	582, 970 base pairs 521 genes

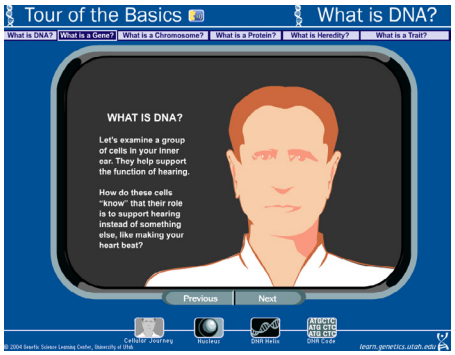
FIELD TRIP STRATEGIES

Before the Field Trip

Explain to students why they are visiting the exhibit and what they will be doing there. Use the interactive floor plan on the website to orient students to the exhibit space and how it is organized.

The exhibit has several touch screen interactives and films that can only be played by one visitor at a time. Develop a strategy on how the students will take turns playing the interactives. One strategy is to give each member of a team a number and they play games in sequence.

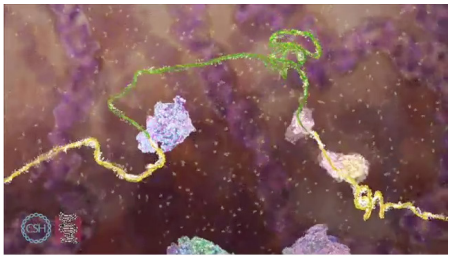
Depending on your curriculum goals and what your students already know about genomics, you can use one or more of the following activities to prepare students and get them excited about the field trip.



1. Review the Basics

"Tour of the Basics," Learn.Genetics, University of Utah
http://learn.genetics.utah.edu/content/begin/tour

This interactive uses simple graphics to answer six questions:
What is DNA? What is a gene? What is a chromosome? What is a protein? What is heredity? What is a trait?



"The Central Dogma of Biology," DNA Learning Center, Cold Spring Harbor Laboratory
http://www.dnalc.org/resources/3d/central-dogma.html

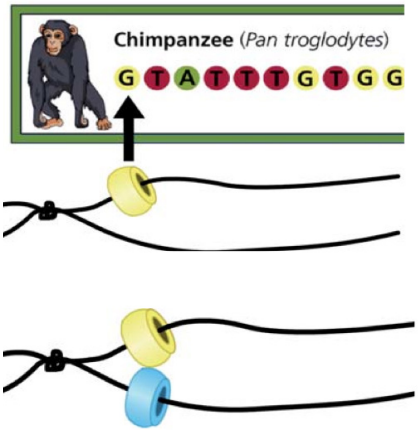
This 3D animation shows how the DNA genetic code leads to proteins that help us develop and function.

2. Make a Model of DNA

Have Your DNA and Eat it Too
http://teach.genetics.utah.edu/content/begin/dna/eat_DNA.html

Students make a strand of DNA with candy or fruit, using different colors to represent the four chemicals and toothpicks to create bonds. When they finish, tell them that the human genome contains more than 3 billion base pairs, and ask them to imagine how long their strand would be if they made that many pairs. Then let students eat their DNA strand.

3. String a DNA Sequence Bracelet



"Sequence bracelets," Wellcome Trust Sanger Institute's yourgenome.org
http://www.yourgenome.org/downloads/pdf/teachers/seq/FT_sequence_bracelets.pdf

Students make simple bracelets that carry part of the code for different organisms such as a human, trout, chimpanzee, carnivorous plant, and hissing cockroach. Each sequence codes for a specific protein. Challenge students to create a mutation and speculate what impact the mutation might have on the protein.

"DNA Code Bracelet," Genome British Columbia
http://www.genomebc.ca/education/activities/dna-code-bracelet

Students create a DNA code for their name, using the DNA ALIAS code for amino acids. They figure out a 3-letter triplet code for each letter in their name, then make bracelets that spell out their name in code.

4. Extract DNA

http://www.youtube.com/watch?v=hOpu4iN5Bh4

Students watch an approximately 10-minute YouTube video in which two staff from the National Human Genome Research Institute of the National Institutes of Health demonstrate how to extract DNA from strawberries.

http://www.genome.gov/Pages/Education/Modules/StrawberryExtractionInstructions.pdf

Students extract DNA themselves using common household supplies and these instructions from the National Human Genome Research Institute.

5. Explore Heredity and Genetic Variation

"Gene Screen" Apps for iPhone and iPad, DNA learning Center, Cold Spring Harbor Laboratory
http://www.dnalc.org/resources/genescreen/

Gene Screen is a fun way to learn how recessive genetic traits and diseases are inherited and how certain diseases are more prevalent in different populations.

"The Gene Scene," Centers for Ocean Sciences Education Excellence (COSEE-West) Resource adapted from Illinois Biodiversity Basics, Illinois Department of Natural Resources, Chicago Wilderness, World Wildlife Fund
http://www.usc.edu/org/cosee-west/Mar08/13TheGeneScene.pdf

Students first identify and classify genetic traits using a genetic wheel and then explain why genetic diversity may be necessary for the long-term survival of a population of animals and plants.

Photo: Don Hurlbert, Smithsonian Institution

At the Museum and Back in the Classroom

Choose one of the following **two activities** to guide students' exploration of the exhibit and follow up on the exhibit experience back in the classroom. Students can also post their newsletter at #genomezone

activity A Genome Newsletter

Students take on the role of science reporters who have been given the assignment to write and produce a newsletter on the genome.

Divide the class up into investigative teams of four to six students, and assign each team to investigate one of the following **three topics**.

HISTORY

- what events and achievements led up to the sequencing of the human genome, including some of the renowned scientists involved
- what the sequencing of the human genome has taught us about the history of our own species, *Homo sapiens,* and our families
- what events shaped our understanding of the world around us

IMPACT

- how the research on the human genome has affected the health and well-being of individual human beings and society as a whole
- what impact the human genome project has had on understanding the natural world around us
- what impact the research on the genome may have on students themselves in the future

CAREERS & TECHNOLOGY

- what kinds of things genomics researchers do, and what kinds of careers are available in this field
- what new technologies have been developed in the field of genomics
- what type of careers were needed to make this exhibit a success

▶ At the Museum:

Make sure each student has a notebook and pencil to collect information.

Students can either take photographs in the museum to include in the newsletter, or make a list of things in the exhibit they would have a photographer shoot.

▶ Modification:

A student can be asked to be the artist for a team. The team can assign the student an exhibit element to draw and label.

▶ Back in the Classroom:

1. Tell students that each team will be responsible for producing an article on the topic they were assigned. Have the teams meet to:
   - discuss the material they collected
   - decide what article content would be the most interesting and informative
   - determine what additional research they need to collect
2. Assign each student a role in producing the newsletter. Roles could include:
   - Reporters: Write the articles
   - Editors: Edit and polish the draft articles
   - Researchers: Collect additional information as needed to supplement what students gathered at the exhibit
   - Graphic designers: Plan the layout of the newsletter, including images
3. Decide on a name for the newsletter.
4. When the newsletter is finished, students can deliver on-line or printed versions to other classes in the school as well as to their families and friends.

Reporter's name: **Assignment date:**

Genome: Unlocking Life's Code

ASSIGNMENT SHEET HISTORY TEAM

Your assignment is to investigate the exhibit *Genome: Unlocking Life's Code* and uncover the following information about the sequencing of the human genome:

- how many years it took to finally sequence the human genome
- some of the major discoveries and achievements along the way
- some of the important researchers and groups involved
- what the sequencing of different human genomes has taught us about the history of our own species, *Homo sapiens*

Remember:

This is a subject that the public needs to know more about. Make sure to collect information that will make a fascinating news article.

Planning Notes:

Talk with the other members of your investigative team about your strategy for covering the exhibit, and who will do what. Write down your thoughts and ideas here.

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etc.

GENOME UNLOCKING LIFE'S CODE

Reporter's name: **Assignment date:**

Genome: Unlocking Life's Code

ASSIGNMENT SHEET IMPACT

Your assignment is to investigate the exhibit *Genome: Unlocking Life's Code* and uncover the following information about research on the human genome:

- some ways that genomic research has affected individual human beings
- how it is affecting society as a whole
- examples of ways it could affect animals, plants, and the natural world
- how it could affect you and your family

Remember:

This is a subject that the public needs to know more about. Make sure to collect information that will make a fascinating news article.

Planning Notes:

Talk with the other members of your investigative team about your strategy for covering the exhibit, and who will do what. Write down your thoughts and ideas here.

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Reporter's name: **Assignment date:**

Genome: Unlocking Life's Code

ASSIGNMENT SHEET CAREERS & TECHNOLOGY

Your assignment is to investigate the exhibit *Genome: Unlocking Life's Code* and uncover the following information about careers and technology in the field of genomics:

- examples of the kinds of things that modern genetic researchers get to do
- who are some modern genetic researchers, and what have they learned or done
- what careers are available in the field of genomics
- what are some of the new technologies that have been developed in the field of genomics
- what technology and devices scientists have used in addition to sequencing machines

Remember:

This is a subject that the public needs to know more about. Make sure to collect information that will make a fascinating news article.

Planning Notes:

Talk with the other members of your investigative team about your strategy for covering the exhibit, and who will do what. Write down your thoughts and ideas here.

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etc.

GENOME UNLOCKING LIFE'S CODE

activity B Discover the Genome Revolution

Students use a worksheet to collect information about some of the important discoveries scientists have made about the genome. Students use the information they uncover to carry out a variety of activities back in the classroom.

In the Museum:

Have students use the Discover the Genome Revolution worksheet on pp. 20–23 to record some of the secrets that researchers have uncovered about the human genome and start thinking about the implications of these discoveries. The worksheet is arranged and color-coded to correlate with the three major sections of the exhibit:

The Genome Within Us

Health

The Natural World

Tell students to make sure the information they collect is accurate because they will need it for activities back in the classroom.

Back in the Classroom:

1. Role Play a Genomics Researcher

Remind students of the scientists whose names and accomplishments they wrote down on their worksheets. Have students do more research on the scientists they selected and write short character sketches describing:

- when that scientist lived
- what he or she was curious about
- what he or she accomplished, and why it was important
- what the world would be like if this scientist had not made his or her discovery

Students can consult the "Timeline of the Human Genome" on the exhibit website (http://unlockinglifescode.org/timeline) to see where each scientist fits in time.

Then have students role play their scientists for the rest of the day. They can brag about their accomplishments in person or in tweets, explain what they hope to do next, or even create a blog.

Rosalind Franklin, Credit: National Library of Medicine NIH

2. Have a BLAST

Remind students of the exhibit activity in which they lined up rows of letters to create a DNA sequence for hemoglobin. Have them write down the sequence of A, T, C, and G for the entire hemoglobin sequence. Then have them use the on-line BLAST program to determine if the sequence is the sickle cell variant.

- Open the BLAST tutorial <http://digitalworldbiology.com/dwb/Tutorials/Entries/2009/1/26_BLAST_for_Beginners.html> in a separate web browser window. Adjust the windows in order to view the tutorial in one browser window and use BLAST in the other window.
- Open the NCBI<http://www.ncbi.nih.gov/> site in a third window. This is where students will do the BLAST search.
- Type in the sequence and discover if it is the sickle cell variant of the hemoglobin protein.

3. Find Mutations that Cause Cancer

Remind students of the exhibit section on mutations that cause breast cancer. Explain that breast and all cancers occur due to abnormalities in the DNA sequence.

Have students use real genomic data from the Cancer Genome Project at the Wellcome Trust Sanger Institute (see link below) to find mutations in a gene associated with pancreatic cancer. Students make the locations of the mutations on a gene sequence banner and record the results. A PowerPoint presentation introducing the topic of cancer accompanies the activity.

"KRAS: Cancer Mutation," Wellcome Trust Sanger Institute's yourgenome.org
http://www.yourgenome.org/teachers/kras.shtml

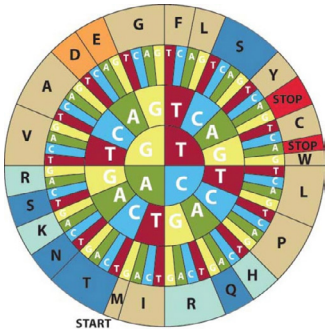


Image: C. Brooksbank, European Bioinformatics Institute

4. Consider Some Ethical Issues

Have students describe some of the ethical issues related to genomics that were raised in the interactive "What Do You Think?" List them on the board.

Divide students into debate teams, and assign each team one of the topics. Each team should have an equal number of students representing both sides of the issue. Give each team time to think about and prepare its "case," and then 10 minutes to debate the issue.

Finish up by asking students if they can think of any other ethical issues that genomics might raise.

5. Help Save the Tasmanian Devil

Remind students of the Tasmanian devil they saw in the exhibit. Have them describe what researchers have learned by sequencing the genome of the contagious cancer that threatens this mammal with extinction. What assumptions of the Hardy-Weinberg principle apply to the Tasmanian devil story?

Use the multimedia lesson plan (see link below) developed by the Wellcome Trust Sanger Institute to learn more about the plight of the endangered Tasmanian devil and how genomics may help save the species from extinction. It includes an introductory video, maps, and activities covering the species' decline, the contagious cancer that caused the problem, sequencing the cancer, and efforts to save the Tasmanian devil.

Activity is under development by the Wellcome Trust Sanger Institute.
http://www.yourgenome.org

Photo: Wayne McLean

6. Explore Our Relationship to Neanderthal

Refer students to their drawings or photos of fossils from which researchers extracted Neanderthal DNA. What do students think about the genetic evidence that modern humans mated with Neanderthals and that many of us have Neanderthal DNA?

Find out more about this evidence in a TED talk entitled "DNA clues to our inner Neanderthal" featuring geneticist Svanta Paabo.
http://www.ted.com/talks/svante_paeaebo_dna_clues_to_our_inner_neanderthal.html

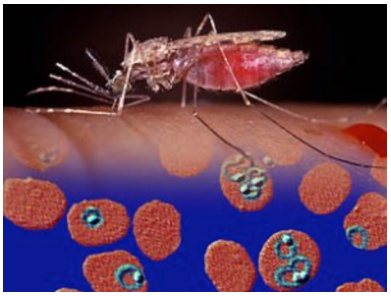
Did this talk change students' opinions?

Source: Max Planck Institute for Evolutionary Anthropology

7. Parasites and Genomics

Remind students of the Chagas disease story they learned about in the exhibit. Have them research and then draw the life cycle of the parasite and explain why understanding the genome of the parasite, the vector, and the host is important.

Use the multimedia lesson plan "Malaria Challenge "(see link below) developed by the Wellcome Trust Sanger Institute to learn more about how genome research is aiding our understanding of parasitic diseases.
http://www.yourgenome.org/teachers/malariachallenge.shtml


Source: The Wellcome Trust Sanger Institute

Explorer's name: **Discovery date:**

Genome: Unlocking Life's Code

DISCOVER THE GENOME REVOLUTION

The Genome Within Us

1. What size is it?

HINT: Look for the "How Big (or Small) Is a Human Genome?" section

- How long would the human genome be if you stretched it out?

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- How many reams of paper would you need to print all the letters in a human genome?

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- How high would the reams reach?

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- Imagine something this large and complex inside every cell of your body. What does it make you wonder?

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2. How long did it take to sequence the first human genome and why did it take so long?

Explore the timeline and videos tracing the events and accomplishments that led up to the completion of the first human genome sequence.

HINT: Look for "The Human Genome Challenge" section

- Why did it take so long?

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- Pick one scientist whose work interests you. Write down his or her name, title, and accomplishment.

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3. What does a genome sequence look like?

Find the genome sequencing puzzle. Follow the instructions on how to line up the six rows of letters to create a strand of DNA.

Congratulations! You pieced together part of the code for making hemoglobin, the protein that carries oxygen throughout your body.

HINT: Look for the "Unraveling the Code" section

- Write down the sequence you created, starting with the farthest letter on the left and ending with the farthest letter on the right.

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4. How is genomics helping to battle cancer?

- Read how genomics led to a drug (Herceptin®) that is helping to treat breast cancer. Using the exhibit images, draw the following cells:

HINT: Look for the "Genomics Changes the Odds" section

normal HER2	excess HER2 protein	treated with Herceptin®

5. How is genomics helping to stop the spread of a deadly disease?

- Draw the bug that kills more than 10,000 people every year.

HINT: Look for the "Stopping the Kiss of Death" section

- What factors in addition to global warming could impact the spread of Chagas disease into the United States?

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- Describe how scientists are hoping to stop Chagas disease in its tracks by using genomics.

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6. What ethical issues does genomics raise?

- Explore the interactive "What Do You Think?" Pick a topic that you feel strongly about. Write down the question and the two points of view. Which do you agree with? Why?

HINT: Look for the "What Do You Think?" interactive

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7. How do the genomes of different organisms compare?

HINT

Look for the "What Comparison Tells Us" section

Compare the genome size of the seven organisms represented.

- Which organism has the largest genome?

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- How does the size of a human genome compare with that of an amoeba?

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- What questions would you ask if you were a genomics researcher?

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8. What can we learn about other species by reading their genomes?

HINT

Look for the "Decoding the Tree of Life" section

- Find the study specimen of a Tasmanian devil in the large display case. Here is what a live Tasmanian devil looks like:

Photo: Wayne McLean

- How does the size of the Tasmanian devil's genome compare with yours?

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- What have researchers learned about this endangered Australian mammal by sequencing its genome?

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9. Are you part Neanderthal?

- Find the casts of the three fossils that researchers used to sequence Neanderthal DNA. Draw or take a photo of them.

HINT

Look for the "Mingling with Ancient Relatives?" section

- What did researchers discover when they compared Neanderthal DNA with the DNA of modern humans?

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- What does this discovery suggest?

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- How do you feel about that discovery?

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- Draw a picture of what Denisovans looked like.

HINT

Look for the "Exploring Our Genomic Ancestry" interactive

10. What can genomics tell us about our ancestry?

- Explore several case studies to find out what people learned by having their DNA tested.

  What kinds of information did they learn?

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- Would you like to have your DNA tested? Why or why not?

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- Would you find out the same information about your ancestry if you were the opposite sex? Explain your answer.

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NEXT GENERATION SCIENCE STANDARDS

A field trip to *Genome: Unlocking Life's Code* supports these Next Generation Science Standards.

For more information on these standards, go to http://www.nextgenscience.org/next-generation-science-standards.

For information on science learning standards in Canada, visit the website for the education department in your province.

MIDDLE GRADE (5–8)

▶ MS-LS1 From Molecules to Organisms: Structures and Processes

MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories. • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	**LS1.B: Growth and Development of Organisms** • Genetic factors as well as local conditions affect the growth of the adult plant.	**Cause and Effect** • Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.

MS-LS3 Heredity: Inheritance and Variation of Traits

MS-LS3-1. Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop and use a model to describe phenomena.	**LS3.A: Inheritance of Traits** Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits. **LS3.B: Variation of Traits** In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism.	**Structure and Function** • Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the relationships among its parts, therefore complex natural structures/ systems can be analyzed to determine how they function.

MS-LS4 Biological Evolution: Unity and Diversity

MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. • Construct an explanation that includes qualitative or quantitative relationships between variables that describe phenomena.	**LS4.B: Natural Selection** Natural selection leads to the predominance of certain traits in a population, and the suppression of others.	**Cause and Effect** • Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.

MS-LS4-5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 6–8 builds on K–5 experiences and progresses to evaluating the merit and validity of ideas and methods. • Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence.	**LS4.B: Natural Selection** In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring.	**Cause and Effect** • Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. **Interdependence of Science, Engineering, and Technology** • Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.

HS-LS1 From Molecules to Organisms: Structures and Processes

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	**LS1.A: Structure and Function** • Systems of specialized cells within organisms help them perform the essential functions of life. • All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells.	**Structure and Function** • Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

HS-LS1 Heredity: Inheritance and Variation of Traits

HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Ask questions that arise from examining models or a theory to clarify relationships.	**LS1.A: Structure and Function** • All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins. **LS3.A: Inheritance of Traits** • Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function.	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. • Make and defend a claim based on evidence about the natural world that reflects scientific knowledge, and student-generated evidence.	• In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. • Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.	**LS3.B: Variation of Traits** • Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.	**Scale, Proportion, and Quantity** • Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

GLOSSARY

For more detail and additional definitions, see the National Human Genome Research Institute's Talking Glossary of Genetic Terms.

Adaptation	A trait with a functional role in the life history of an organism, evolved and maintained by natural selection.
Allele	One of two or more versions of a gene. An individual inherits two alleles for each gene, one from each parent.
Amino acids	A set of 20 different molecules used to build proteins.
Base pair	Two chemical bases bonded to one another and forming a rung of the DNA ladder.
Cancer	A group of diseases characterized by uncontrolled cell growth.
The Cancer Genome Atlas (TCGA) (http://cancergenome.nih.gov/)	A project begun in 2005 to catalogue genetic mutations responsible for cancer, using genome sequencing and bioinformatics. TCGA is applying genome analysis techniques to improve our ability to diagnose, treat, and prevent cancer.
Cell	The basic building block of living things.
Chromosome	An organized package of DNA found in the nucleus of the cell. Humans have 23 pairs of chromosomes. Each parent contributes one chromosome to each pair.
DNA (Deoxyribonucleic Acid)	The chemical name for the molecule that carries genetic instructions in all living things.
DNA sequencing	A laboratory technique used to determine the exact sequence of bases in a DNA molecule. The DNA base sequence carries the information a cell needs to assemble protein and RNA molecules, and is important to scientists investigating the functions of genes.
Double helix	The description of the structure of a DNA molecule: two strands that wind around each other like a twisted ladder and that are held together by bonds between the bases.
Gene	The basic physical unit of inheritance. Genes are passed from parents to offspring and contain the information needed to specify traits. Humans have approximately 20,000 genes arranged on their chromosomes.
Genetic Information Nondiscrimination Act (GINA)	Federal legislation that makes it unlawful to discriminate against individuals on the basis of their genetic profiles in regard to health insurance and employment. President George W. Bush signed GINA into law on May 22, 2008.
Genetics	The study of a particular gene in an organism.
Genome	The entire set of genetic instructions found in a cell.
Genomics	The study of the entire genome of an organism.
Heredity	The transmission of physical or mental traits from one generation to the next through the genes.

Human Genome Project	An international project that mapped and sequenced the entire human genome. It was completed in April 2003.
Lactose intolerance	The inability to digest lactose, a sugar found in milk and, to a lesser extent, milk-derived dairy products. It is a genetically-determined characteristic, not a disorder.
Microbiome	All the genetic material found within a microbe such as a bacterium, fungal cell, or virus. May also refer to the collection of genetic material in a community of microbes.
Mitochondrial DNA	The small, circular chromosome found inside mitochondria (organelles in cells that are sites of energy production). Mitochondria and mitochondrial DNA are passed from mother to offspring.
Molecule	A group of two or more atoms that are bonded together and that can take part in chemical reactions.
Mutation	A change in a DNA sequence, caused by DNA copying mistakes, exposure to certain kinds of radiation or chemicals, or infection from viruses. Some mutations can be passed on to offspring.
Nucleus	The cell's command center—a membrane-bound structure that contains the cell's chromosomes.
Pharmacogenomics	A branch of pharmacology that uses DNA and amino acid sequence data to inform drug development and testing. One important application is correlating individual genetic variation with drug responses.
Protein	Proteins are an important class of molecules found in all living cells. A protein is composed of one or more long chains of amino acids, the sequence of which corresponds to the DNA sequence of the gene that encodes it. Proteins play a variety of roles in the cell, including structural (cytoskeleton), mechanical (muscle), biochemical (enzymes), and cell signaling (hormones). Proteins are also an essential part of diet.
Risk	In the context of genetics, the probability that an individual will be affected by a particular genetic disorder. Both genes and environment influence risk.
Trait	A specific characteristic of an organism, determined by genes or by the environment or, more commonly, by interactions between the two.

OTHER RESOURCES

For additional teacher resources organized by specific topics, visit the Online Genetics Education Resources database on the *Genome* exhibit website: http://unlockinglifescode.org/learn/resources-teachers.

Websites with a Variety of Resources

Biointeractive, Howard Hughes Medical Institute, http://www.hhmi.org/biointeractive/

The Howard Hughes Medical Institute hosts a Holiday Lecture on Science series. Leading medical researchers explain how advances in genomics are revolutionizing their work and leading to a better understanding of disease. The site has a collection of animations, videos, and interactives. The Stickleback Evolution Virtual Lab features a species in the *Genome* exhibit's *Tree of Life* section.

DNA Learning Center (DNALC), Cold Spring Harbor Laboratory, http://www.dnalc.org

DNALC is the world's first science center devoted entirely to genetics education. It is a unit of Cold Spring Harbor Laboratory, an important center for molecular genetics research. DNALC maintains 21 websites as well as collections of media for middle school and other audiences.

Genome British Columbia, http://www.genomebc.ca/education/education-overview/

Genome BC seeks to inform British Columbians about the science and wonder of genomics and to provide tools for discussing the implications of research. Resources for teachers include educational animations, hands-on activities, information articles, student worksheets, and traveling exhibitions.

Learn.Genetics, Genetic Science Learning Center, The University of Utah, http://learn.genetics.utah.edu

The Genetic Science Learning Center is a science and health education program located in the midst of bioscience research being carried out at the University of Utah. The Learn.Genetics website delivers educational materials on genetics, bioscience, and health topics for use by students, teachers, and members of the public.

Teach.Genetics, Genetic Science Learning Center, The University of Utah, http://teach.genetics.utah.edu

Teach.Genetics is the second website maintained by the Genetic Science Learning Center. Designed to support and extend the materials on Learn.Genetics, it includes PDF-based activities, unit plans, and other supporting resources for K–12 teachers, higher education faculty, and public educators.

Your Genome, Wellcome Trust Sanger Institute, http://www.yourgenome.org

Maintained by the Wellcome Trust Sanger Institute, a charitably funded genomic research center in the United Kingdom, this website offers videos featuring leading researchers, explanatory animations, downloadable classroom activities, and basic information about genetics and genomics.

PBS Teacher Resources, http://www.pbslearningmedia.org/search/?q=Genome

This site is a compilation of interactives, videos, and lesson plans, including a chromosome viewer and a video of geneticist and rock musician Pardis Sabeti.

Northwest Association for Biomedical Research (NWABR), http://nwabr.org/teacher-center

NWABR has an extensive lesson archive including full plans, rubrics, and guidelines. It also provides a variety of professional development programs to promote understanding of biomedical research. The focus is on bioethics and bioinformatics.

The Future is in Our Genes, Ontario Genomics Institute, http://www.ontariogenomics.ca/outreach/genomics-classroom

This site includes lesson plans that explore some of the key events in the history of genomics, study microarrays without expensive equipment, and explore scientific and ethical issues relating to genetic testing.

UDACITY, Tales from the Genome, http://www.udacity.com/course/bio110

This free 12-lesson on-line course is a journey into the biology of the human genome. It highlights the scientific, social, and personal perspectives of people living with a variety of traits. Topics include fundamental principles of inheritance, gene expression, mutation and variation, development of simple and complex biological traits, human ancestry and evolution, and the acquisition of personal genetic information.

The Learning Network's "Hunger Games" Science: Investigating Genetically Engineered Organisms, http://www.learning.blogs.nytimes.com/2012/05/16/hunger-games-science-investigating-genetically-engineered-organisms/

Case Studies

National Center for Case Study Teaching in Science, University of Buffalo, http://sciencecases.lib.buffalo.edu/cs/

The National Center for Case Study Teaching in Science promotes the development and dissemination of materials and practices for case teaching in the sciences. The website provides access to an award-winning collection of peer-reviewed case studies—including more than 50 on topics related to genetics and genomics.

Science Fair Project Ideas

Science Buddies, http:// www.sciencebuddies.org/

Science Buddies has over 1,000 ideas for science fair projects, including *Use DNA Sequencing to Trace the Blue Whale's Evolutionary Tree* and *The Cancer Genome Anatomy Project. Who Has the Biggest Genome?* is a great fit with the *Genome* exhibit.

TED Talks

This award-winning video site features talks by some of the world's most fascinating thinkers and doers. Here are some of the talks directly related to the content of the Genome exhibition.

The Genome Within Us

Richard Resnick, *Welcome to the Genome Revolution*

Quote: "The price to sequence a base [of the human genome] has fallen 100 million times. That's the equivalent of you filling up your car with gas in 1998, waiting until 2011, and now you can drive to Jupiter and back twice."
http://www.ted.com/talks/richard_resnick_welcome_to_the_genomic_revolution.html?quote=1064

Barry Schuler, *Genomics 101*

Quote: "We are all 99.9 percent genetically equal. It is one one-hundredth of one percent of genetic material that makes the difference between any one of us. By being able to write a genome and plug it into an organism, the software, if you will, changes the hardware."
http://www.ted.com/talks/barry_schuler_genomics_101.html

Juan Enriquez, *Will our kids be a different species?*

Quote: "I think we're going to move from a *Homo sapiens* into a *Homo evolutis*: … a hominid that takes direct and deliberate control over the evolution of his species, her species and other species."
http://www.ted.com/talks/juan_enriquez_on_genomics_and_our_future.html

Health

Francis Collins, *We need better drugs now*

Quote: "Today we know the molecular cause of 4,000 diseases, but treatments are available for only 250 of them. So what's taking so long?"
http://www.ted.com/talks/francis_collins_we_need_better_drugs_now.html

Jay Bradner, *Open-source cancer research*

Quote: "We know that there are perhaps 40,000 unique mutations affecting more than 10,000 genes and that there are 500 of these genes that are bonafide drivers —causes—of cancer. Yet comparatively we have about a dozen targeted medications."
http://www.ted.com/talks/jay_bradner_open_source_cancer_research.html

The Natural World

Svante Paabo, *DNA clues to our inner Neanderthal*

Quote: "When we look at people and see a person from Africa and a person from Europe or Asia, we cannot, for a single position in the genome, with 100 percent accuracy, predict what the person would carry."
http://www.ted.com/talks/svante_paeaebo_dna_clues_to_our_inner_neanderthal.html

Ellen Jorgensen, *Biohacking–You can do it, too*

Quote: "You might be asking yourself, 'What would I do in a biolab?' Well, it wasn't that long ago we were asking, 'What would anyone do with a personal computer?'"
http://blog.ted.com/2013/01/15/alaska-or-bust-ellen-jorgensen-barcodes-plants-in-a-remote-national-park/

Hendrik Poinar, *Bring back the woolly mammoth!*

Quote: "That doesn't mean it's the right thing to do...As much as the kid in me would love to see these fantastic species plundering across the north, it's hard to see a reason why we should unless we think this technology could give us tools for conservation."
http://www.ted.com/talks/hendrik_poinar_bring_back_the_woolly_mammoth.html

Ted-Ed

Judith Hauck, *The twisting tale of DNA*

What do a man, a mushroom, and an elephant have in common? A very long and simple double helix molecule makes us more similar and much more different than any other living thing. But how does a simple molecule determine the form and function of so many different living things?
http://ed.ted.com/lessons/the-twisting-tale-of-dna-judith-hauck

Harvey Fineberg, *Are we ready for neo-evolution?*

Medical ethicist Harvey Fineberg provides three paths forward for the human species: to stop evolving completely; to evolve naturally; or to control the next steps of human evolution, using genetic modification to make ourselves smarter, faster, and better. Neo-evolution is within our grasp. What will we do?
http://ed.ted.com/lessons/are-we-ready-for-neo-evolution-harvey-fineberg

Joe Hanson, *DNA: The book of you*

Your body is made of cells—but how does a single cell know to become part of your nose, instead of your toes? The answer is in your body's instruction book: DNA. Joe Hanson compares DNA to a detailed manual for building a person out of cells, with 46 chapters (chromosomes) and hundreds of thousands of pages covering every part of you.
http://ed.ted.com/lessons/dna-the-book-of-you-joe-hanson

YouTube Videos

Human Prehistory 101, 23andme, http://www.youtube.com/playlist?list=PL2EE0E7F5240634EB

This five-part award winning series starts with the history of early humans 200,000 years ago and moves on to how agriculture changed human societies and genetics.

What is a Genome? http://www.youtube.com/watch?v=rvryNYlbfKA

This winner of the RCSU Science Challenge 2013 is an excellent overview for middle school students.

RACE: Are We So Different? **The American Anthropological Association,**
http://www.youtube.com/watch?v=8aaTAUAEyho

This video tells stories of race from the biological, cultural, and historical points of view. Combining these perspectives offers an unprecedented look at race and racism in the United States.

Educator Guides

The Field Museum Education Department's The Daniel F. and Ada L. Rice DNA Discovery Center
http://archive.fieldmuseum.org/dna/pdf/DNA_Guide.pdf

Cold Spring Harbor's DNAi Teacher Guide
http://www.dnai.org/teacherguide/guide.html

Howard Hughes Medical Institute's Teacher Guide: DNA
http://www.hhmi.org/biointeractive/teacher-guide-dna

Knex Education's Teacher Guide, DNA, Replication and Transcription
http://cdn.teachersource.com/downloads/lesson_pdf/KNX-500TeachersGuide.pdf

European Learning Laboratory for the Life Sciences' Teacher's Guide to Microarray Exercise
http://emblog.embl.de/ells/wp-content/uploads/2011/10/teacher_microarray.pdf

Dean Madden NCBE, University of Reading's DNA to Darwin
http://www.dnadarwin.org/casestudies/intro/FILES/IntroTG1.0.pdf

The Exploratorium's DNA Files Workshops
http://www.exploratorium.edu/dnafiles/series.html

Developers of Genome: Unlocking Life's Code

This exhibit was developed by the National Institutes for Health's National Human Genome Research Institute and the Smithsonian Museum of Natural History in association with Science North.

The National Human Genome Research Institute supports research to study the human genome and its role in health and disease, and to examine the ethical, legal, and social implications of genetics.

NIH National Human Genome Research Institute

The National Museum of Natural History is the world's most visited natural history museum, with enormous collections that include a frozen tissue bank that preserves DNA samples from a diversity of life.

Smithsonian
National Museum of Natural History

Science North, Northern Ontario's most popular attraction, is a leader among science centers in providing inspirational, educational, and entertaining science experiences.

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